UNCLASSIFIED

AD 444705

DEFENSE DOCUMENTATION CENTER

FOR

SCIENTIFIC AND TECHNICAL INFORMATION

CAMERON STATION, ALEXANDRIA, VIRGINIA

UNCLASSIFIED

REPORT 319

REPORT 319

ADVISORY GROUP FOR AERONAUTICAL RESEARCH AND DEVELOPMENT

64 RUE DE VARENNE, PARIS VII

802730

AD No. 444705

DDC FILE COPY

REPORT 319

FLIGHT TEST TECHNIQUES AND INSTRUMENTATION FOR VTOL AIRCRAFT

by

R. J. TAPSCOTT

APRIL 1961

NORTH ATLANTIC TREATY ORGANISATION

62-08-5075

REPORT 319

~~NORTH ATLANTIC TREATY ORGANIZATION~~

5 ADVISORY GROUP ~~FOR~~ AERONAUTICAL RESEARCH ~~AND~~ DEVELOPMENT,

Paris (France).

6 FLIGHT TEST TECHNIQUES AND INSTRUMENTATION FOR VTOL AIRCRAFT,

10 by

Robert J. Tapscott,

D.C.

This Report was presented at the Nineteenth Meeting of the AGARD Flight Mechanics Panel, held from 17-19 April 1961 in Paris, France

SUMMARY

A discussion is presented of the basic measurements were made in flight with VTOL aircraft to explore the new regimes of flight involved and to develop design criteria and operating techniques in the new regimes. In many cases, the actual flight procedures discussed are similar to those used for other types of aircraft. The exploratory nature of the VTOL flight testing, however, frequently calls for special planning with respect to safe methods for conducting the flight tests, procedures for demonstrating the distinctive characteristics, and suitable recording instrumentation. The importance of pilot orientation in order that he may provide accurate observations and opinions to the engineer is discussed particularly in regard to the many qualitative aspects of the VTOL flight programs conducted to date.

SOMMAIRE

Cette communication a pour but de présenter un exposé des mesures fondamentales réalisées en vol sur les avions VTOL, en vue d'étudier les nouveaux régimes de vol mis en jeu, et d'élaborer des critères de calcul et des techniques d'exploitation convenant à ces nouveaux régimes. Dans la plupart des cas, les procédures de vol traitées ici sont analogues à celles utilisées pour d'autres types d'avion. Toutefois, la nature exploratrice des essais en vol des avions VTOL demande souvent l'organisation de méthodes spéciales permettant la conduite en toute sécurité des essais en vol, de procédures pour mettre en évidence les caractéristiques particulières, et d'instruments d'enregistrement convenables. L'importance de la formation du pilote en vue de lui permettre de faire à l'ingénieur des observations et des opinions précises est traitée à l'égard, plus particulièrement, des nombreux aspects qualitatifs des programmes d'essais en vol VTOL entrepris jusqu'à présent.

533.652.6:533.6.05

3c6d

CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

FLIGHT TEST TECHNIQUES AND INSTRUMENTATION FOR VTOL AIRCRAFT

Robert J. Tapscott*

1. INTRODUCTION

In recent years a considerable number of VTOL-type aircraft have emerged. A wide range of configurations has been proposed and built by the various organizations; many of these have passed from the initial flight-demonstration phases into more general flight research programs for the study of their peculiar requirements and novel features. From these programs a more thorough study is being made of the handling qualities and performance characteristics, as well as the structural load variations, for the various VTOL concepts.

In the United States, the N.A.S.A. is presently conducting flight research on a number of these flying test beds to accumulate information on the flying and handling qualities of the various design concepts. The purpose of this paper is to provide some discussion of the techniques used and instrumentation required to obtain the necessary data from a flight project of this type.

2. FLIGHT RESEARCH PROJECT ORGANIZATION

An over-all picture of the procedure generally used to conduct a flight project at N.A.S.A. may be obtained by reference to Figure 1. Three main types of personnel work together very closely with the specific plans for the flight project, beginning usually before the aircraft is physically at hand. Along with the project engineer, there is a pilot-engineer, who conducts the actual flights, and an instrumentation specialist, who sets up the instrumentation according to the requirements of the project. In most flight projects, and particularly those involving handling qualities or exploratory studies, the pilot takes a very active and important part in the entire program. It is almost an essential requirement for the pilot to have the specific orientation and training to permit him to have a thorough understanding of the program. His understanding should include the principles involved as well as a knowledge of what the data obtained during the specific maneuvers are intended to show and how they will be analyzed and interpreted. Under these conditions, the pilot's experience can be used in the planning and he is in a better position to provide the engineer with good observations and opinions. The heavy lines on Figure 1 represent loosely the flow of information and discussion taking place on a flight-to-flight basis, starting with a written flight request for a given flight and resulting in the engineering data desired.

It should not be inferred from Figure 1 and the preceding discussion that each flight project has available such abundance of manpower as the full time of these three people. Each of these three would more than likely be involved concurrently in similar manner with one or more other such projects and personnel.

**Aeronautical Research Engineer, NASA Langley Research Center, Langley Field, Virginia, U.S.A.*

3. FLIGHT TECHNIQUES FOR MEASUREMENTS

Table I shows the more frequently measured parameters to define hovering controllability, static stability and trim characteristics, aerodynamic flow effects, and dynamic behavior. Tabulated, also, are the techniques used, the pertinent data-recording channels and, briefly, the method of examining or presenting the data.

3.1 Initial Response to Control in Hovering

In the flight regimes of hovering and very low airspeeds, the aerodynamic forces have only small influence on the stability characteristics of the aircraft. Under these conditions, the characteristics of the controls and the initial response of the aircraft to control inputs become of primary importance. The parameters which contribute most heavily to the control characteristics in these conditions are the control moment produced for a given movement of the pilot's control and the angular velocity damping or restoring moment proportional to angular velocity. A technique for measuring both of these parameters for a given axis in a single flight maneuver is generally used. It involves making a step-input with the given controls and recording the resulting angular velocity response of the aircraft. Figure 2 illustrates a typical response obtained in this manner. The two parameters of interest with respect to the time history are the initial slope of angular velocity record, which represents the angular acceleration, and the steady value of angular velocity, which is a measure of the ratio of the applied control moment to the damping moment. Thus, this response record provides a measure of the two primary response parameters, control power and damping. Control inputs of varying magnitude are generally made, with the viewpoint of averaging out extraneous effects and of defining any nonlinear characteristics.

The validity of this procedure for determining damping moment is based on the assumption that the initial response of the aircraft is that of a first-order system. The specific technique for making the control input involves a false start in one direction until an attitude change results, then a reversal of direction of the control step. In this way the steady angular velocity occurs when the aircraft is more nearly in a level attitude and the effect of sideslip or forward motion is minimized. Experience has shown that for most aircraft, in hovering and at very low airspeeds, this technique provides a fairly accurate measure of the aircraft response parameters. If, however, the damping moment is unstable, the response may be divergent and measurements cannot be made directly by the technique described.

A considerable amount of study has been directed toward establishing criteria for satisfactory initial response characteristics at hovering and very low airspeeds. The results of studies made with a variable-response helicopter are reported in Reference 1 and provide the basis for control-response criteria which are published in Reference 2. Studies of the type discussed in the previous paragraph subsequently made with several other VTOL configurations have borne out the general applicability of these criteria in establishing minimum response characteristics for low-speed flight.

3.2 Static Stability and Trim Characteristics

3.2.1 General

The ensuing discussion of techniques for determining the characteristics of an aircraft is premised on the use of continuous recording instrumentation with synchronized timing. The specific parameters of interest with respect to each phase of the study will, in general, be indicated in the discussion. Specific details and descriptions of available recorders of interest with respect to the various parameters can be obtained by reference to the data in the Appendices.

One important point, which is common to the measurements, is that of obtaining data by slowly varying a given parameter, such as airspeed or sideslip angle, while recording continuously with time that parameter and the other associated parameters. Cross-plotting the appropriate parameters at frequent time intervals yields a well-defined curve showing the stability slopes. This method is discussed in more detail in Reference 3 and offers considerable saving of flight time; for example, the directional stability at a given condition can be completely defined over a $\pm 30^{\circ}$ sideslip range in about 2 minutes of flight, whereas, if steady conditions were established and recorded at a sufficient number of discrete sideslip angles, many times this amount of flight time would have been necessary. The rule of thumb generally observed with respect to this method is to limit the rate at which variations are made to about 1°/sec for angular changes or 1 knot/sec for airspeed changes to prevent dynamic effects from showing up in the measurements. With this method the practice is to make the variation slowly and continuously over the entire range from trim to maximum change in one direction, then back through trim to maximum change in the opposite direction and back to trim. The data curves can be noted for each direction, and effects of a too rapid rate of change may show up as a 'hysteresis' loop. There are other limitations with respect to the use of this method in specific circumstances and some such limitations will be brought out in later discussion.

With the aircraft currently being studied, not much emphasis has been placed on the control force variations, not necessarily because these lack importance but because the other characteristics of the newer configurations are likely to be more basic in nature; thus, most of this discussion is related to stick-fixed characteristics.

3.2.2 Speed Stability

It is important to note, with respect to setting up a flight procedure to measure the speed stability of a given configuration, that the variation in speed must be accomplished with no change in the power setting or configuration. The slope of the curve of stick position plotted against airspeed will then be indicative of the moment change on the aircraft due to inadvertent airspeed changes. For most configurations this procedure will result in the aircraft climbing or descending in accordance with the variation of power required for level flight with airspeed as the airspeed is varied. One case, in particular, where the method of slow continuous variation of parameters to obtain stability slopes was found useless, was the measurement of speed stability at very low speeds in a rotor configuration. This was a case in which the vertical velocity was apparently very sensitive to power variations, while at the same time large variations in trim stick position occurred with vertical velocity at a given airspeed. Figure 3 shows the variation of control position with

airspeed obtained when the slowly varying airspeed technique was attempted under these circumstances. Apparently, the small amount of energy differential between the accelerating and decelerating directions due to the inertia effects resulted in large differences in vertical velocity at a given airspeed, with the attendant large variations in control position.

3.2.3 Directional Stability and Dihedral Effect

The data needed to define slopes of directional, or weathercock, stability and dihedral effect (roll moment due to sideslip), can be obtained at the same time by performing sideslips while recording the pedal and stick lateral movements. Figure 4 shows the directional characteristics of an aircraft where combinations of several methods were useful in establishing the final curves. In ranges where the weathercock stability is positive, data taken during slow, continuous variation of sideslip angles provided a well-defined stability curve. For the range of sideslip angles where the aircraft was unstable directionally, a large amount of scatter was apparent in the data and well-defined slopes were difficult to obtain. Under these conditions the range of instability can generally be demonstrated by establishing a sideslip angle in the unstable range, fixing the controls and recording the subsequent limit of divergence of the aircraft in sideslip angle and/or heading and yawing velocity. Fortunately, in many cases, as in the case illustrated, such directional instabilities exist over only a small range of sideslip angles and extreme conditions do not result. In more severe cases of instability, such as have been experienced with some configurations, care must be exercised by the pilot to prevent the divergence from proceeding to the catastrophic situation where the control is no longer powerful enough to overcome the unstable moments.

3.2.4 Trim Changes and Power Effects

In isolating control displacements involved in opposing moments which arise from changes in configuration or flight condition, a systematic coverage of most of the flight envelope of the aircraft is required. With conventional aircraft it has generally been found sufficient to maintain constant airspeed while power and/or configuration changes were made. With the VTOL types, however, because of the additional variables involved, additional techniques had to be used to completely cover the various possible combinations of angle-of attack, power airspeed and configuration that could be obtained in the conversion flight range. Various techniques were tried and several were ultimately used to obtain data which, when suitably cross-plotted, represent the characteristics of the aircraft, insofar as they affect the pilots' opinion of the handling qualities. Of these, one consisted of maintaining level flight and constant fuselage attitude throughout the airspeed range while converting from hovering to cruise configuration. Another was to hold power and fuselage attitude constant while the conversion was accomplished at varying rates. Still another maneuver was to hold both airspeed and fuselage angle of attack constant while the power (i.e., vertical velocity) was varied throughout the feasible range. The first two techniques tended to highlight trim variations in the conversion range and provide data which could be used to establish the transition 'corridor' limits; i.e., usable combinations of airspeed, conversion angle, power, rates of deceleration and acceleration. The third procedure was more in the nature of defining the usable range of descent or climb angles through establishing, in particular, the limiting rates of descent for given airspeeds or conversion angles. For the tilt-wing

configuration specifically, this procedure has been used to establish fairly well-defined boundaries with respect to the effects of flow separation on the wing. In this case, as the power was reduced slowly, the reduced slipstream effects eventually resulted in separated or unsteady flow over the wing.

In each instance, over a range of airspeeds from about 25 to 70 knots, there existed a limiting rate of descent beyond which further power reduction could not be made because of deterioration of stability characteristics and erratic uncontrollable motions of the aircraft.

Figure 5 shows the boundaries with respect to the effects of stall for the tilt-wing configuration. The plot shows the limiting combinations of airspeed and vertical velocities for two test configurations due to the adverse effects of wing-flow separation on the handling qualities. Simultaneously with the recording of the data, which established the aircraft behavior as these limits were approached, the action of wool tufts attached to the wing surface was recorded by the motion-picture camera mounted on the vertical tail.

Another aspect of the power effects which warranted study was the variation of power required with speed in the conversion region. Much consideration has been given from time to time on the effects on handling qualities of having to operate on the backside (i.e., unstable variation with speed) of the power-required curve. By exploration of the variation of power required under various conditions, it was established that by use of the proper technique for some configurations, landing approaches could be made in the low-speed range under conditions where a stable power variation with speed was present. Figure 6, for example, shows the variation with power required for a tilting-duct VTOL aircraft under two conditions, as noted on the figure. It is seen that at a constant duct angle, in this case the trim duct angle for about 50-knot airspeed, the speed could be varied over a range of about 10 knots with a stable speed power variation. Thus, for the manner in which the aircraft would normally be flown, i.e., fixed configuration and use of attitude changes to maintain desired speed, conditions could be selected so as to operate with a stable speed-power variation.

3.3 Maneuver Stability

In studying the maneuver stability characteristics of the newer VTOL configurations, at low speeds in particular, much of the flight procedure has been based on the earlier techniques worked out for the helicopter. The use of the longitudinal pull-and-hold test maneuver to document the maneuver characteristics, or divergence tendencies, is discussed more fully in References 4 and 5 in connection with helicopter studies. The pull-up maneuver was designed as a substitute for the wind-up turn procedure and is generally used at the lower airspeeds where high angular rates are present for small bank angles and 'g' forces. Two parameters become of importance with respect to handling qualities insofar as this maneuver is concerned. These are the normal acceleration and the pitching angular velocity. At the higher speeds, where significant changes in lift can be made by changing angle of attack, the maneuver stability characteristics appreciated by the pilot can be related to the buildup of the normal acceleration following a pull-and-hold (i.e., step deflection) of the longitudinal control. At the lower speeds, where a change in attitude of the aircraft does not produce appreciable lift or change in flight path, the buildup and peaking of the pitch angular velocity becomes the primary parameter. In each case the basic criterion for acceptable maneuver

stability is that evidence be present in the time histories, within 2 seconds from the start of the maneuver, of eventual peaking of the normal acceleration and/or pitching angular velocity. It should be stressed at this point that the time histories of these parameters during the test maneuvers are not, in themselves, the specific characteristics the pilot appreciates with respect to over-all maneuvering flight. Experience has shown, however, that the specific shape of these time histories can be correlated with the pilots' opinion of the characteristics of the aircraft in general maneuvering and rough-air flight and provides a numerical representation of the maneuver stability characteristics.

3.4 Dynamic Characteristics

3.4.1 Longitudinal

For the most part, stick-fixed longitudinal oscillations tend to involve simultaneous changes in airspeed, attitude, and angle of attack. Thus, it is difficult to delineate the oscillatory characteristics of the VTOL configurations, particularly at low airspeeds, with respect to the classical concepts of short-period and phugoid oscillations. In general, however, two distinct techniques are used in flight to produce oscillations. The first involves an abrupt control pulse intended to produce a disturbance in angle of attack or attitude at constant airspeed. The second also involves a control pulse, but of somewhat longer duration and intended to produce a disturbance of airspeed. In each case, the resulting oscillation can generally be defined with respect to period and damping by the recorded time histories of the normal acceleration and pitching angular velocity. Figure 7 shows, for example, the variations with airspeed of the period of the longitudinal oscillation of the tilt-wing VTOL aircraft. This plot was determined from time histories of the pitch angular velocity following pulse inputs with the stick.

In some cases any control-induced oscillations expand at such a rapid rate as to appear almost a pure divergence in the initial cycle. Also, in the presence of static instabilities, control pulses may result in a pure divergence. It is difficult under these circumstances to obtain a time history of any length sufficient for quantitative answers to define the stability characteristics. It may then be desirable to supplement these data by obtaining records in both smooth and moderately rough air wherein the pilot fixes the controls at trim for as long as he can tolerate, while the ensuing buildup of motions of the aircraft is recorded.

3.4.2 Lateral Directional

Study of the lateral-directional handling qualities, in addition to the static stability discussed in a previous section and the conventional 'Dutch roll' oscillations, includes primarily the characteristics during pedal-fixed turns (i.e., by use of lateral control only). Figure 8 shows typical time histories of such a maneuver, one illustrating a response which was related to unsatisfactory turn entry characteristics and the other illustrating the response existing with marginally satisfactory characteristics. In the case of the unsatisfactory characteristics, the time histories show that the roll angular velocity reversed within a few seconds after the control input in what appears to be the beginning of an expanding oscillation. For the marginal case, the roll angular velocity time history is convergent and, although it reduces to zero, no roll velocity is built up in the opposite direction.

4. INSTRUMENTATION

The recording instrumentation systems are similar, in general, for most of the flight projects and are built up to suit the needs of a specific project from a stock of various types of sensors and recorders. The various individual instruments and components are described in Appendices A-P and will not be discussed in detail here; however, it is desired to point out that considerable effort is directed toward a functional, but not necessarily refined, recording system to gain the most from the relatively expensive flight time. With respect to the instrumentation for special purposes, it has frequently been found desirable, for example, to install two completely separate airspeed systems, for both recording purposes as well as for indications to the pilot. In this way, only, could the needed range be covered with sufficient sensitivity being maintained at the very low airspeeds. One particularly useful type of airspeed sensor for low, near zero, and rearward airspeeds, is shown in Appendix A. This type sensor was particularly adapted to sensing a component of airspeed in the presence of helicopter rotor downwash.

Figure 9 shows the general locations of the instrumentation installed in a tilt-wing VTOL aircraft for recording purposes and is typical of the recording installations used.

Due to the many combinations of variables which the pilot sometimes has to monitor during the flight tests, it has been found necessary frequently to install special panel instrumentation for the pilot. Figure 10 shows a general view of the cockpit panel in the tilt-wing aircraft. During the exploratory phases of flight, for example, such indications as control positions, sideslip angle, and angle of attack have been useful and are included on the panel shown. One of the most useful of panel instruments with respect to setting up test conditions has been a commercially available rate-of-climb instrument which combines a pressure signal and accelerometer signal to give an instantaneous reading of vertical velocity.

5. SAFETY OF FLIGHT CONSIDERATIONS

A discussion of the flight-test experience with the current generation of VTOL configurations would not be complete without some mention of the consideration that was given to the safety of flight. Because the studies with some of these vehicles frequently included flight conditions in which they had not been previously operated, the safety aspects played a major part in establishing the sequence of the test coverage. In most cases, prior to the initial flights, the estimated hovering response parameters, i.e., the control power and damping were set up in a variable-response helicopter (see Reference 1) and the pilot was given in-flight familiarization with the characteristics which he might find in the test vehicle. These practice flights were flown with relative safety with another pilot along in the second cockpit who could take over with the helicopter's normal controls, if necessary.

The sequence of test flights was arranged in such a manner as to gradually expand the envelope of flight conditions. Stresses and amounts of control used for trim and maneuvers were monitored on a flight-to-flight basis during the feeling-out process. Safe boundaries were established in this manner for the trim limits in decelerating flight and for the limits of controllability with respect to effects of flow separation

in reduced-power descents, directional capabilities, and limits of the instabilities. During this procedure, data were accumulated with respect to aerodynamic characteristics, handling qualities, and operational capabilities and techniques. From this point on, the flights became a relatively routine program conducted within the established limitations of the vehicle to fill in the gaps in the data already obtained or to obtain specific data on such items as proposed fixes for various deficiencies and/or alternative methods of control.

6. CONCLUDING REMARKS

The specific flight techniques used for study of the various aircraft are by no means rigidly set down. Frequently, after the start of a program, in which specific plans had been made with respect to the coverage, techniques, and data desired, changes were more nearly the rule than the exception. In most cases to date, the vehicles which have been available for study with respect to VTOL operation have had serious limitations, particularly in regard to control margins and thrust-to-weight ratios, and component life; however, the various techniques described in this paper have permitted an accumulation of considerable knowledge of use to a designer of this type of aircraft. A great deal of the data have been qualitative; however, they are useful for future planning purposes with respect to research and development, aircraft design, and operational aspects.

REFERENCES

1. Salmirs, Seymour, Tapscott, Robert, J. — *The Effects of Various Combinations of Damping and Control Power on Helicopter Handling Qualities During Both Instrument and Visual Flight.* NASA TN D-58, 1959.

2. Tapscott, Robert, J. — *Criteria for Control and Response Characteristics of Helicopters and VTOL Aircraft in Hovering and Low-Speed Flight.* Institute of Aero-Space Sciences Paper No. 60-51, January 1960.

3. Johnson, Harold, I. — *A Comparison of Data Obtained by Two Flight Techniques for Determining Sideslip Characteristics of a Fighter Airplane.* NACA WR L-87. (Formerly NACA RB L5F25a.)

4. Amer, Kenneth, B. — *Method for Studying Helicopter Longitudinal Maneuver Stability.* NACA TN 3022, 1953.

5. Reeder, John, P. — *Notes on Helicopter Research.* Presented to AGARD Flight Test Panel, Paris, Nov. 29 - Dec. 4, 1954.

TABLE I

Summary of Characteristics Measured During Flight Study

Characteristic	*Technique*	*Data Recorded*	*Presentation of Data*
Initial response to control	Step inputs of varying magnitude	Control positions; aircraft angular velocities	Angular acceleration versus control deflection; angular velocity damping values
Speed stability	Slow variation of airspeed about trim (power, configuration, other variables held constant)	Stick longitudinal motion; airspeed	Plots of stick longitudinal positions as function of airspeed
Directional stability; dihedral effect	Slow variation of sideslip angle at constant airspeed (rate of change of sideslip angle less than 1°/sec)	Pedal and stick lateral motions; sideslip angle	Plots of pedal and stick lateral positions as functions of sideslip angle
Trim changes and power effects; aerodynamic flow characteristics	Conversion in level flight with fuselage attitude constant; conversion with constant power and fuselage attitude; power variation at constant airspeed and conversion angle	Power; aircraft angular velocity; angle of attack; stick and pedal motion; camera record of tuft action on various surfaces	Cross plots of airspeed, vertical velocity (see Figure 5)
Maneuver stability	Pull-up maneuver; wind-up turn	Stick motion; normal acceleration; pitch angular velocity	Time histories of normal acceleration and/or pitch angular velocity
Dynamic stability	Abrupt control pulse; airspeed disturbance; fixed controls	Control motion; airspeed; angle of attack; angular velocity	Variation of periods and damping with flight condition

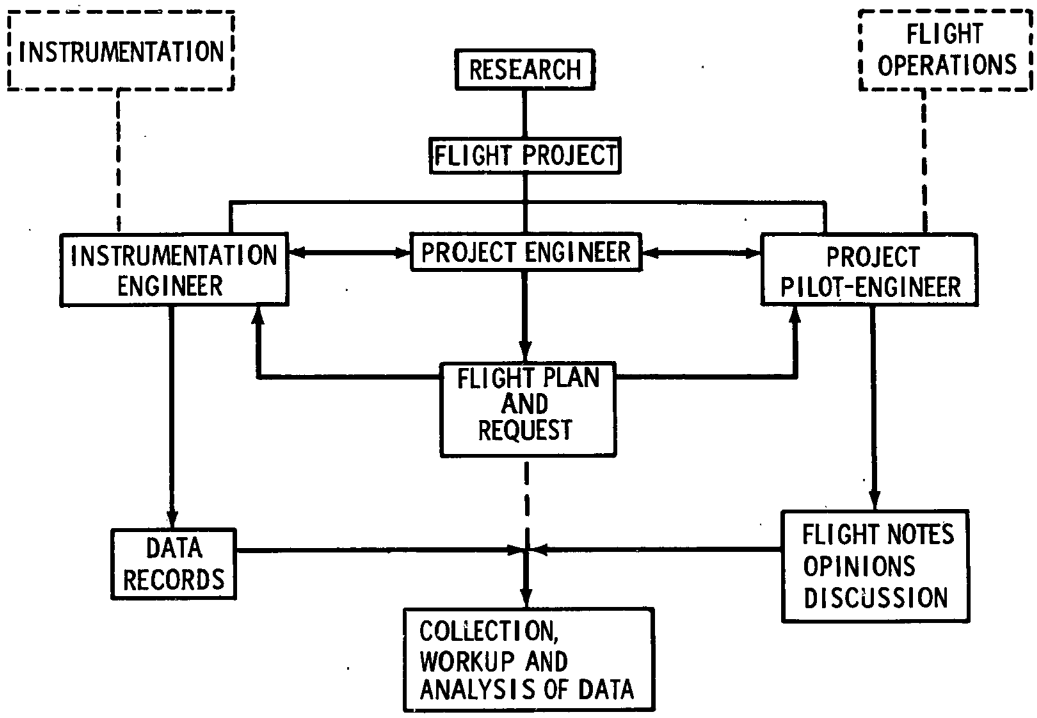


Fig.1 Flight research project organization

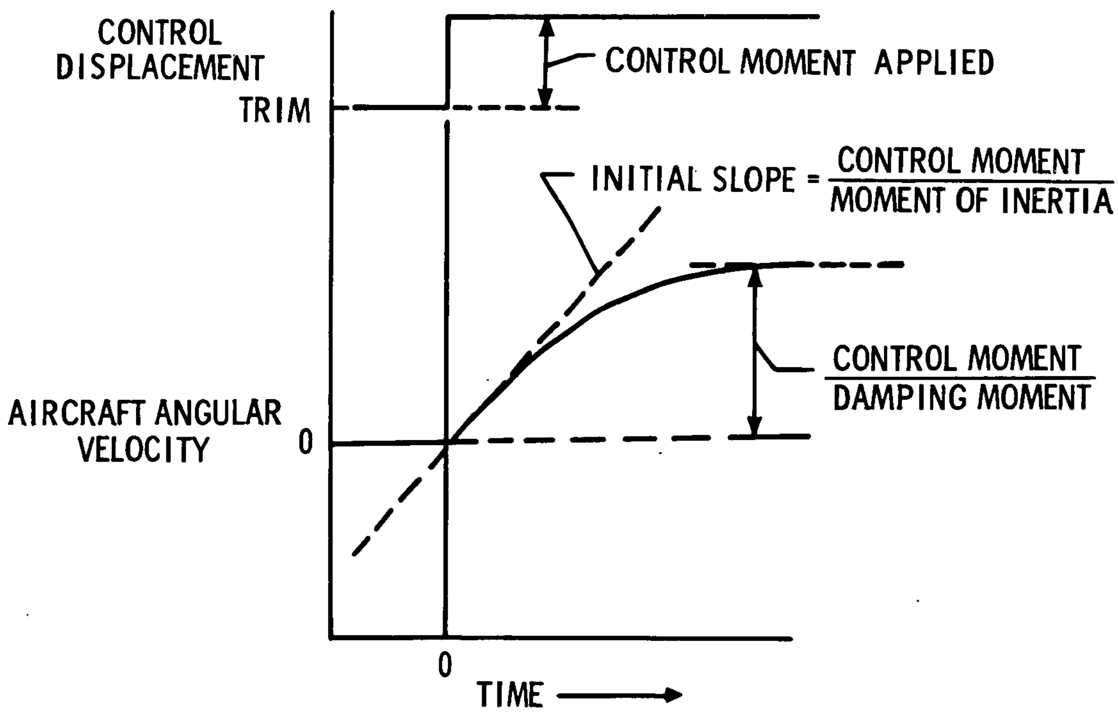


Fig.2 Time histories for determining control and damping moments in hovering

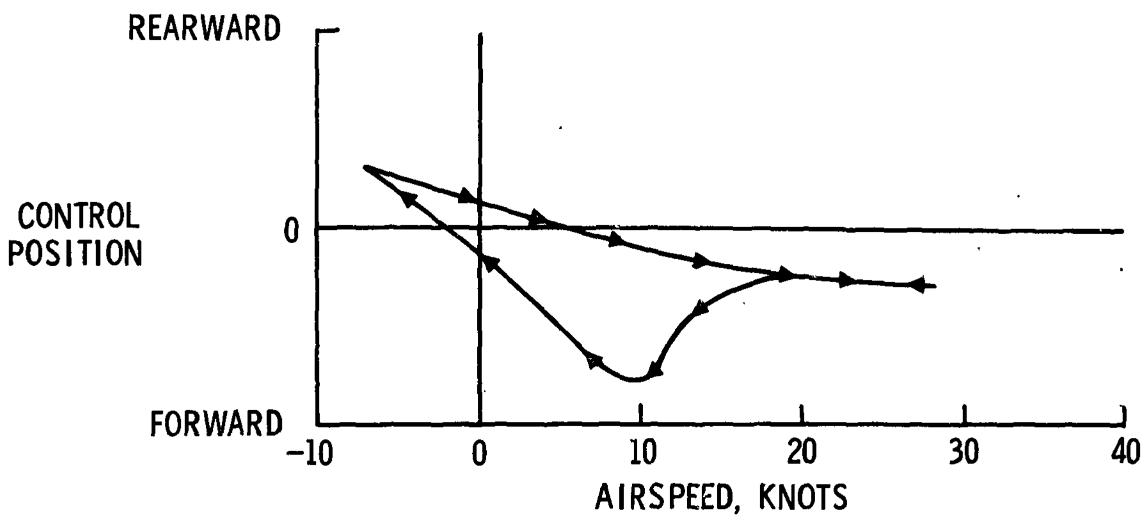


Fig.3 Attempted speed stability measurements

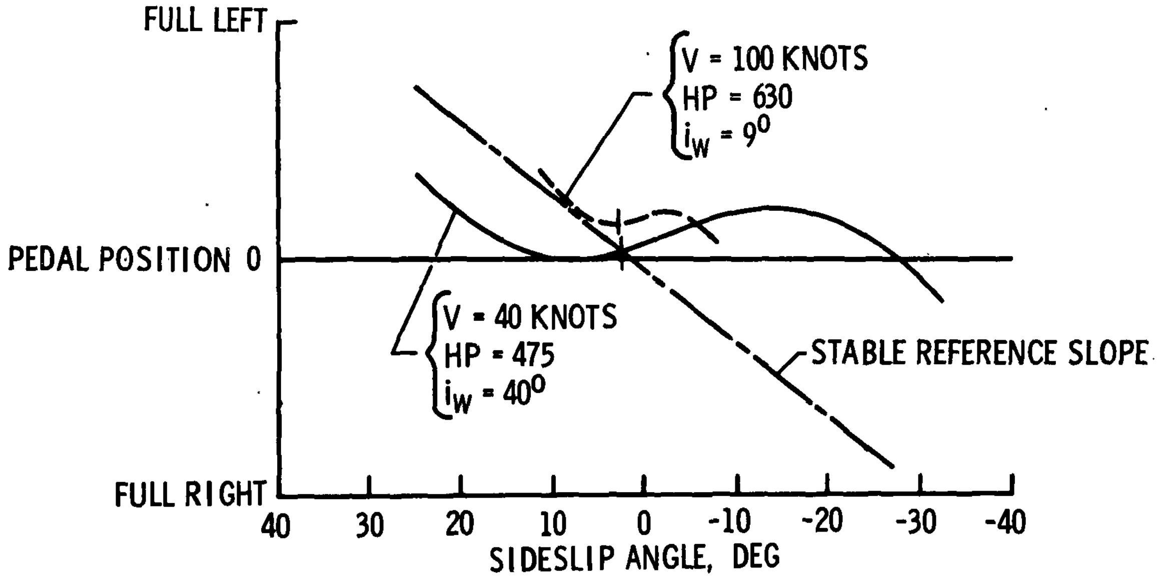


Fig.4 Static directional stability characteristics. Tilt-wing aircraft

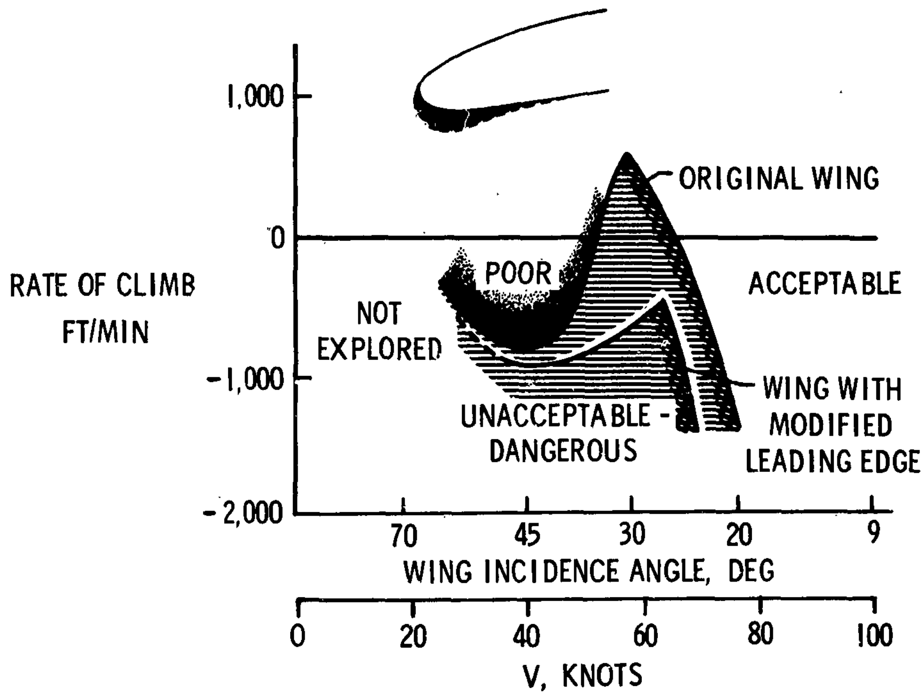


Fig.5 **Rate-of-descent limitations due to stalling. Tilt-wing aircraft**

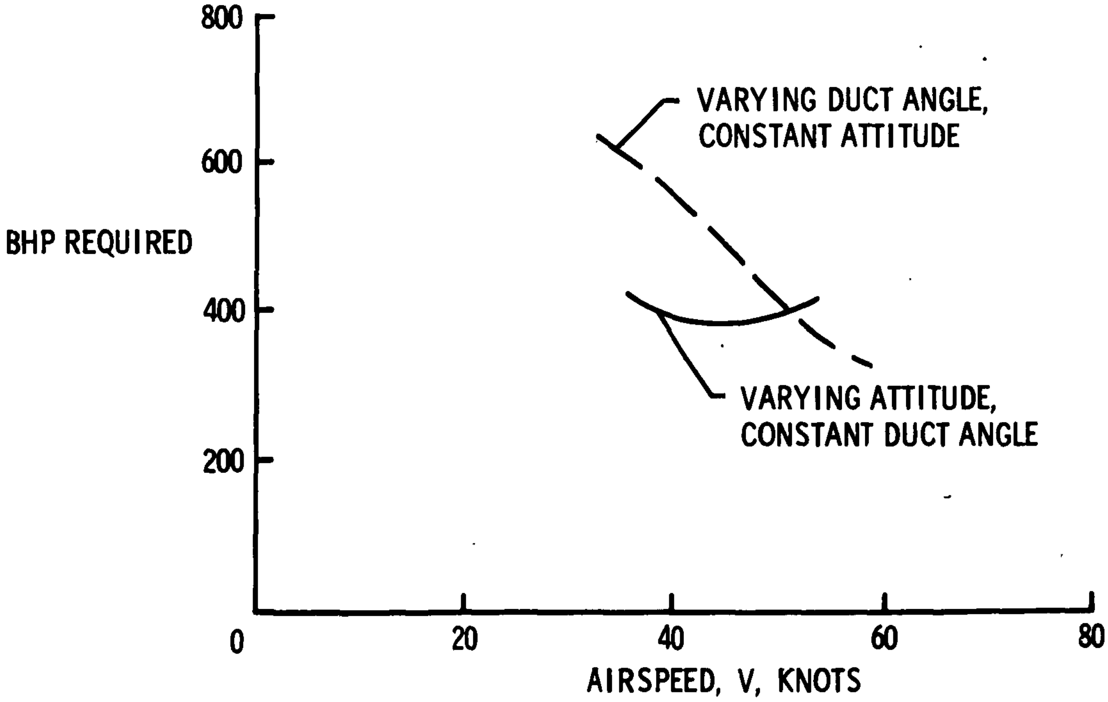


Fig.6 **Power required for level flight. Tilting-duct aircraft**

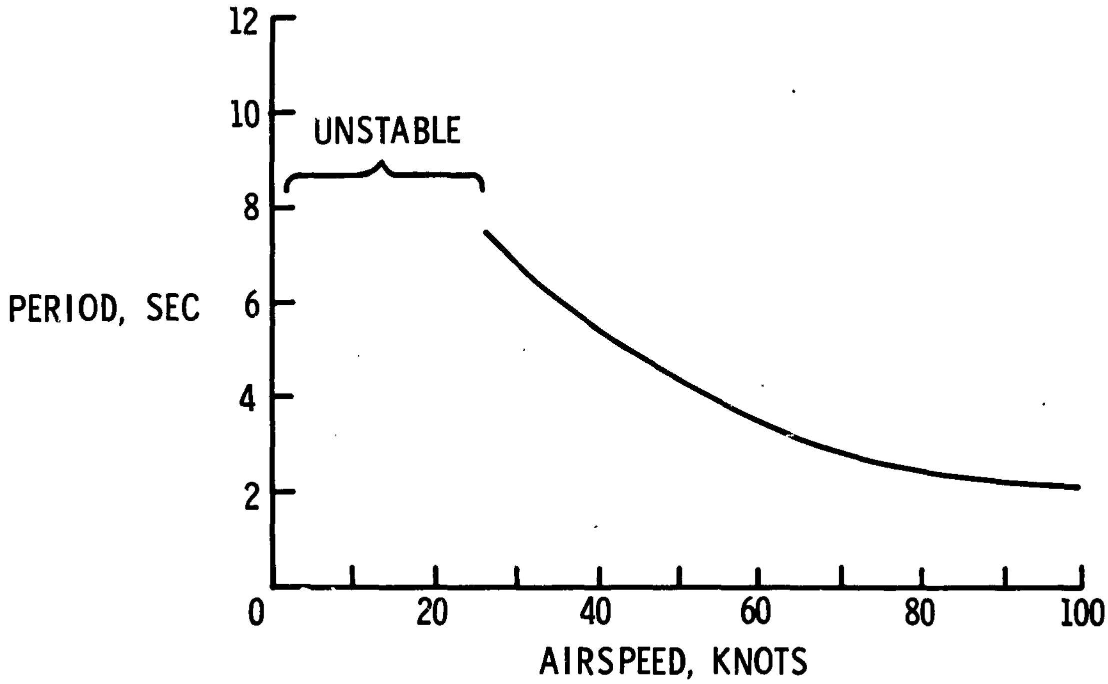


Fig.7 Period of longitudinal oscillation. Tilt-wing aircraft; approximately level flight

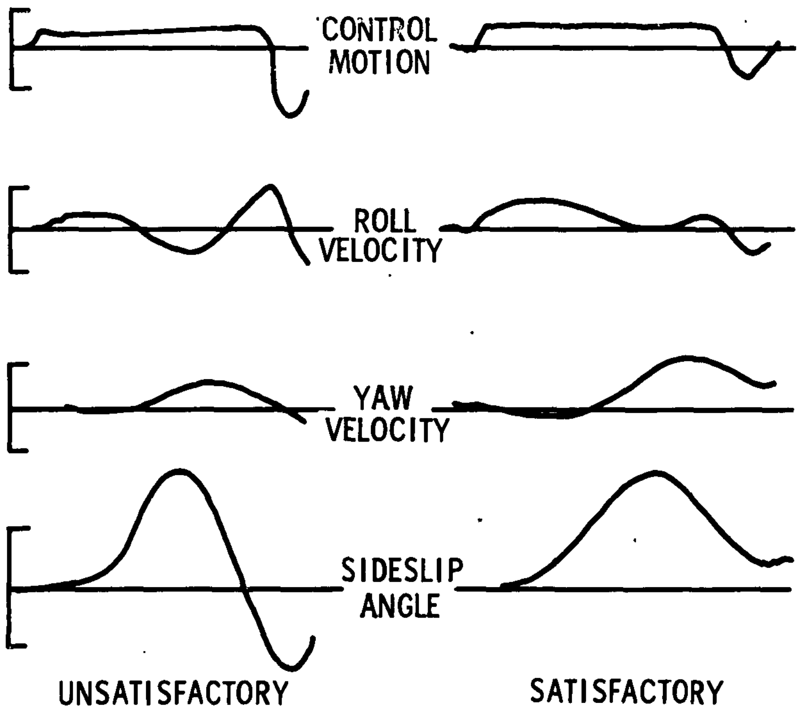


Fig.8 Attempted pedal-fixed turn showing rolling velocity reversal

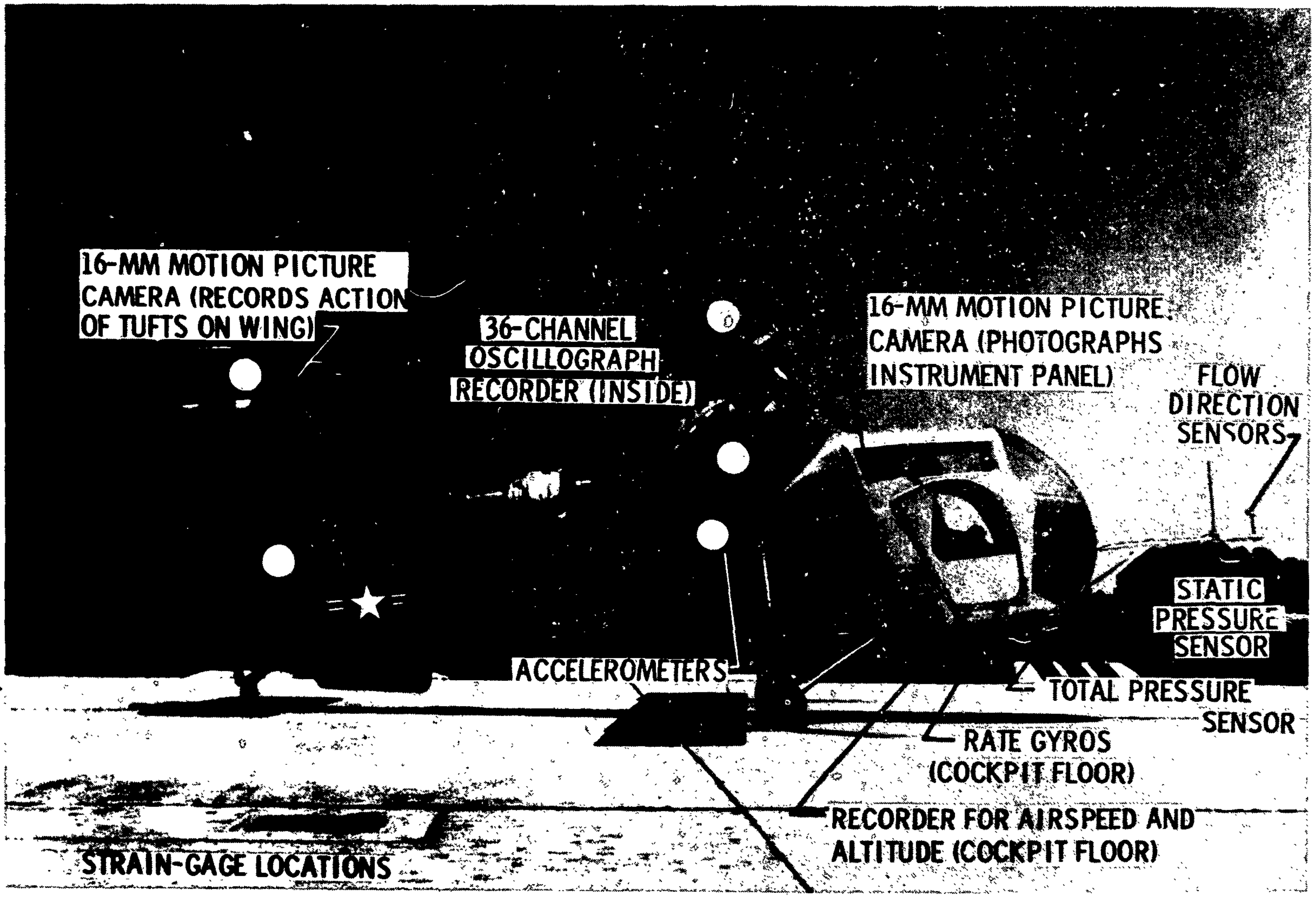


Fig.9 Typical instrumentation

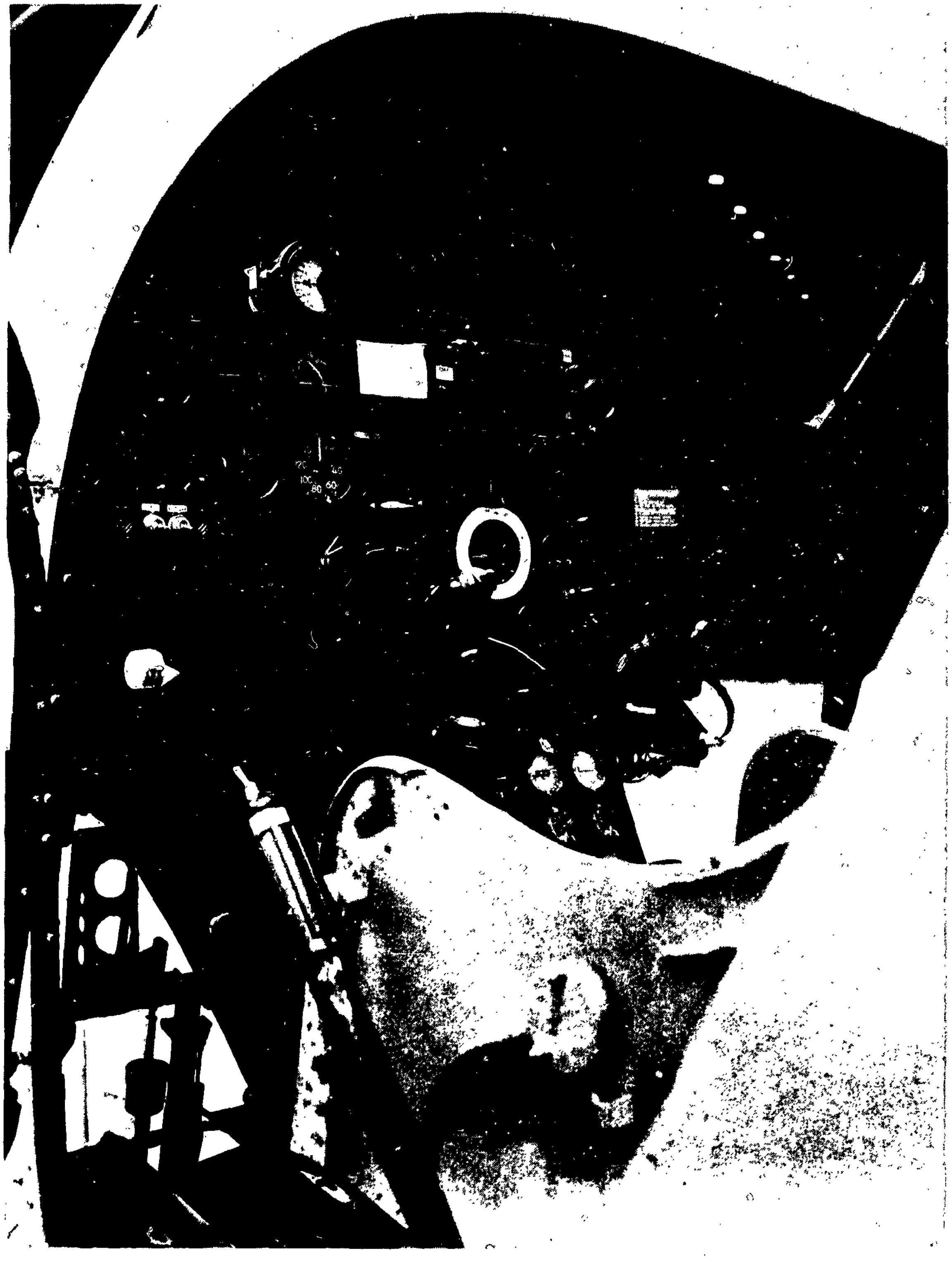


Fig.10 Cockpit of VZ-2

APPENDIX A

Low-Airspeed Sensing System

Measurement of low airspeeds by any device attached to the aircraft is complicated both by the ability of the aircraft to move at large angles to the relative wind and by slipstream effects. The slipstream is distorted by low forward speeds, and spreads far beyond the aircraft when hovering close to the ground.

One installation, which has been of considerable use, particularly with helicopters, involved the use of one or more pairs of shielded double-ended pressure pickups interconnected to provide an average pressure-difference reading.

The pickup tubes (Figure A-1) were designed through wind-tunnel tests with the intent of providing a total-pressure and low-pressure reference source which would measure essentially a component of airspeed along the axis of the tube. For forward airspeeds the forward end of the tubes acted as total-pressure pickups, the rearward end supplying the low-pressure reference. Conversely, for rearward airspeeds the rearward end of the tubes became total-pressure pickups, the forward end acting as reference. Pickup tubes installed at several locations are usually manifolded together to average out the effects of local flow variations and to provide a basically symmetrical system applicable to both forward and rearward airspeeds.

Indicating instruments for use with Pitot-static installations are now available commercially having good sensitivity (a gap of about 1/4 in. width between 0 and 10 knots markings, for example). For use in low-speed flight-test work, the most important modification generally needed for such instruments is to provide some pointer travel below 0 (to prevent inadvertently reaching highly unstable rearward flight conditions while attempting to reach or hold 0 for hovering). Commercial instruments have been modified also to increase the sensitivity in the range 5 to 25 mph. Damping of the pointer motion, when needed, has been achieved by placing capillary tubing in the airspeed lines; the amount needed for balancing with respect to rapid variations in static pressure (due to large rates of climb, etc.) is often adequate. Amounts of damping, however, should not be so large as to cause excessive lags.

Insofar as recording is concerned, by using pressure cells having a range of ±1 in. of water (see Appendix B), sensitivity and accuracy commensurate with other limitations have been obtained.

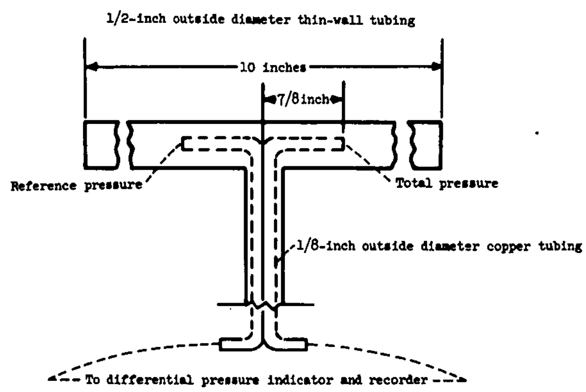


Fig. A-1

APPENDIX B

Temperature-Compensated Airspeed Element

Principle of Operation

The temperature-compensated airspeed element consists of a corrugated diaphragm surrounded by an airtight capsule (Figs. B-1 and B-2). The total-head pressure is applied to the inside of the diaphragm and the static pressure is applied to the inside of the capsule surrounding the diaphragm. The unsupported end of the diaphragm moves almost linearly with respect to the difference in pressure applied across it. The deflection of the diaphragm is transmitted to a pivoted mirror which deflects a beam of light through a lens embedded in the capsule front plate. A fixed mirror is also mounted inside the capsule to provide a reference from which the deflection images are measured. A bimetal lever arm is located on top of the diaphragm to compensate for temperature changes.

Description

Capsule diameter	$2\frac{13}{32}$ in. diameter
Capsule depth	$\frac{7}{8}$ in.
Capsule depth with tube fittings	$1\frac{5}{8}$ in.
Mounting plate	$2\frac{13}{32}$ in. by $2\frac{11}{32}$ in.
Mounting holes	4 holes equally spaced on $2\frac{9}{16}$ in. diameter (clearance of $\frac{3}{56}$ screws)
Weight	152 grams
Range:	
Minimum	5 in. H_2O
Maximum	20 in. H_2O
Diaphragm diameter	Up to 50 in. H_2O: $2\frac{1}{16}$ in. 50 in. H_2O to 20 in. Hg: $1\frac{11}{16}$ in.
Diaphragm full-scale deflection	0.040 in.
Diaphragm air volume	$\frac{2}{10}$ in^3.
Capsule volume with parts in place	0.93 in^3.

Note - Element is suitable for mounting on all standard NASA optical recording airspeed bases and on any of the NASA recording multiple manometers.

Accuracy

Hysteresis and friction	¼%
Temperature effect	±¼% scatter

Acceleration effect at zero pressure, 50 inches H_2O and 100 inches H_2O:

Transverse (along axis of pressure stem)	$\frac{1}{10}$% per g
Vertical	Negligible
Longitudinal	Negligible

Heading accuracy	1 part in 800
Zero stability	No zero shift

Natural frequency of diaphragm:

5 in. H_2O diaphragm	130 c/s
10 in. Hg diaphragm	400 c/s

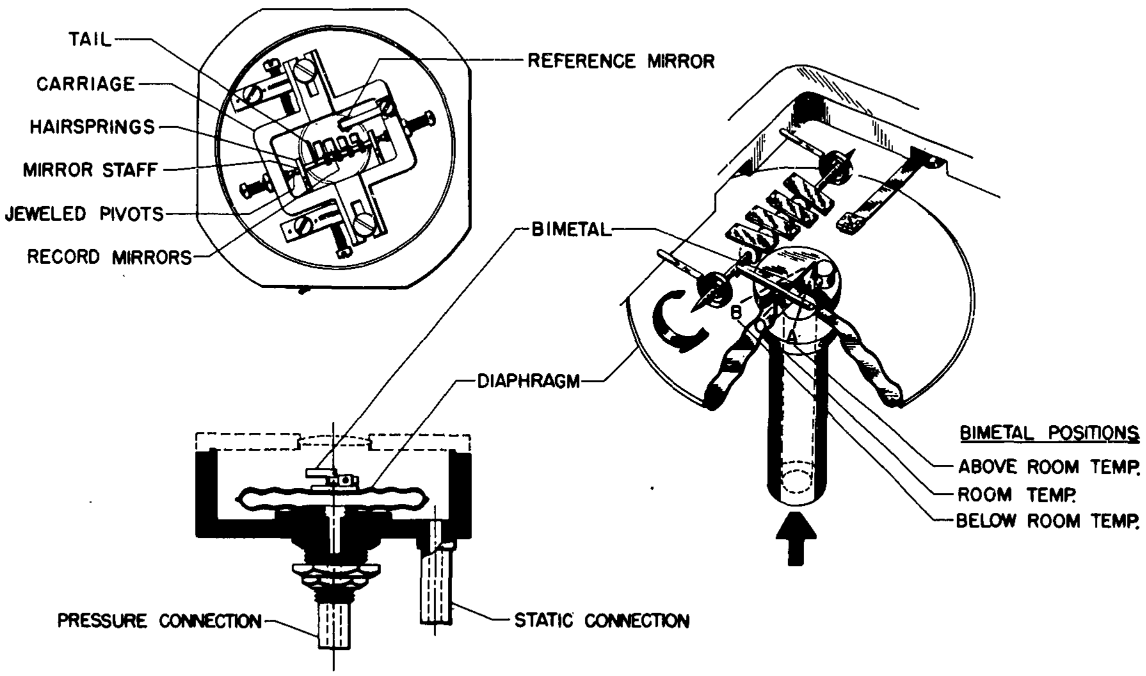


Figure B-1

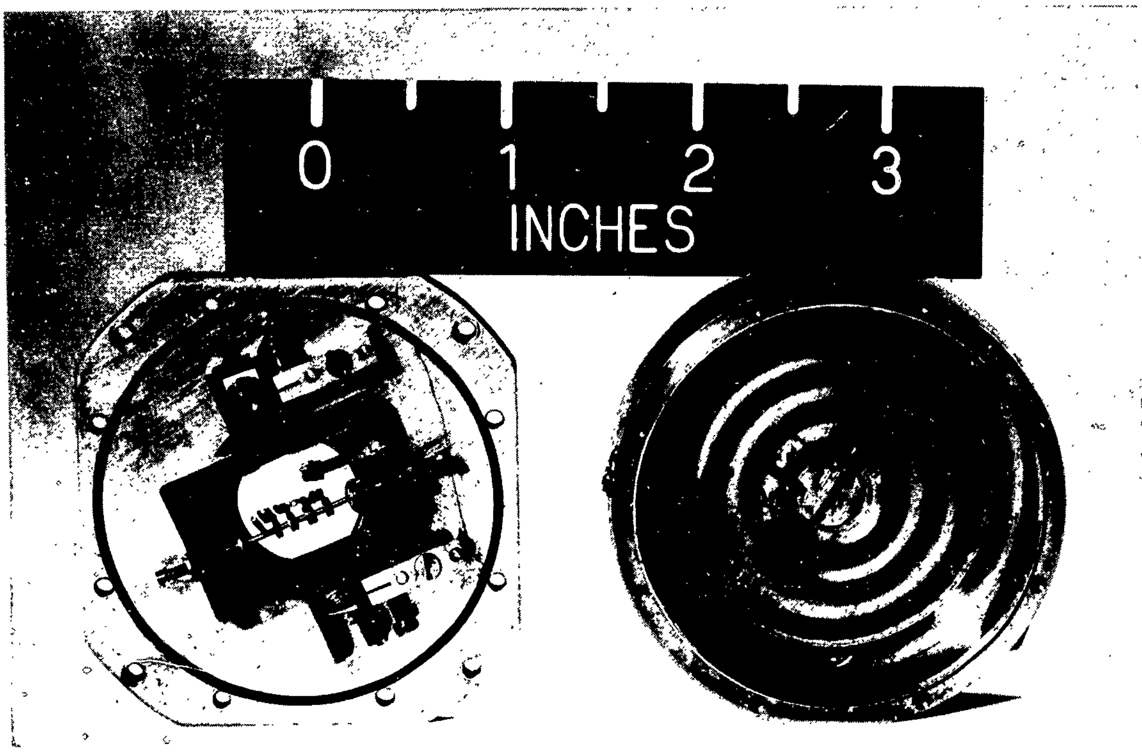


Figure B-2

APPENDIX C

Low Absolute Pressure Element

Principle of Operation

The absolute pressure recording element consists of a corrugated diaphragm assembly surrounded by an airtight capsule. The sensing unit consists of a pair of nesting corrugated diaphragms. The outer diaphragm remained in the mold while the inner one was formed to enable the convolutions to fit perfectly. The outer convolution on the outer diaphragm is then stretched 0.03 in. so, when the diaphragms are soldered together, a 0.03 in. spacing is left between them. 100 mm Hg differential pressure with the high pressure applied to the outside is sufficient to overcome the spring constant and collapses the center of the diaphragm assembly. To be used as an absolute pressure unit, it is totally evacuated on the inside.

When the pressure surrounding the diaphragm is reduced to an absolute pressure of 100 mm Hg, the diaphragms begin to separate. One of the central supports on the diaphragm assembly is attached to the capsule and the other is free to move with variations in pressure below 100 mm Hg. The free end of the diaphragm moves a pivoted mirror which reflects a beam of light through a lens inbedded in the front plate. A fixed mirror inside the capsule provides a reference image on the film from which the deflection image can be measured. The air-tight capsule surrounding the diaphragm assembly has a tube fitting with a 1/4 in. outside diameter, to which the pressure connection is made. A photograph of this arrangement is shown in Figure C-1.

Description

Capsule diameter	$1\frac{21}{32}$ in.
Capsule depth	$\frac{7}{8}$ in.
Capsule depth with fittings	$1\frac{25}{32}$ in.
Mounting plate	$1\frac{21}{32}$ in. by $1\frac{21}{32}$ in.
Mounting holes	Clearance for 2-64 screws 4 holes equally spaced on $1\frac{13}{16}$ in. diameter
Weight	186 grams
Range with 3 mirrors	100 mm
Range with 1 mirror	20 mm (maximum sensitivity)
Diaphragm diameter	$1\frac{9}{32}$ in.

Diaphragm full-scale deflection	2 ranges (0.015 in. and 0.030 in.)
Diaphragm air volume	2 ranges (0.015 in^3. and 0.030 in^3.)
Capsule volume with parts in place	0.5 in^3.

Accuracy

Hysteresis and friction	±¼%
Temperature effects	2% sensitivity change per 100° F; no zero shift
Reading accuracy	1 part in 200 for single mirror, 1 part in 600 for 3 mirrors

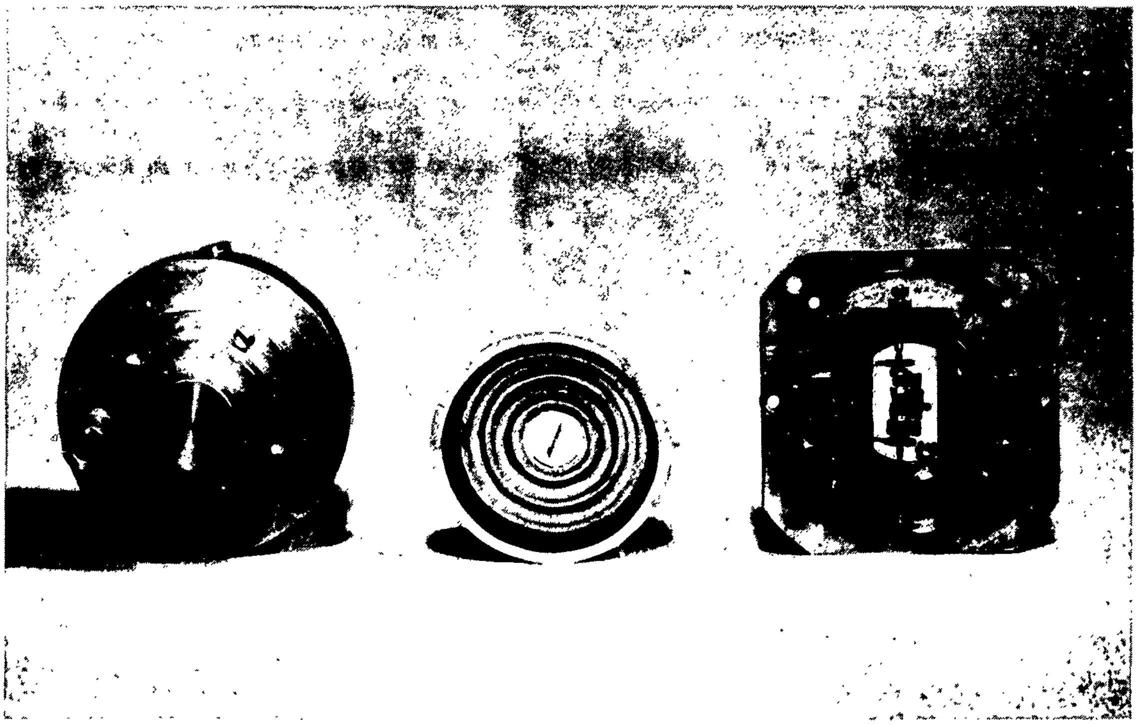


Figure C-1

APPENDIX D

Temperature-Compensated Altimeter

Principle of Operation

The temperature-compensated altimeter element consists of an avacuated corrugated diaphragm surrounded by an airtight capsule (Fig. D-1). One end of the diaphragm is attached to the capsule and the other end is free to move with variations of absolute pressure. The free end of the diaphragm moves a pivoted mirror which reflects a beam of light through a lens enbedded in the capsule front plate. A fixed mirror is also mounted inside the capsule to provide a reference from which the deflection images are measured. These images can be recorded on the standard NACA recording base. The static pressure is connected to the capsule surrounding the diaphragm. The diaphragm used in this element is constructed from an alloy which has very little modulus change for changing temperature. A schematic drawing of the system and a photograph of the element are shown in Figures D-1 and D-2, respectively.

Description

Capsule diameter	$2\frac{7}{8}$ in.
Capsule depth	$1\frac{7}{32}$ in.
Capsule depth with tube fitting	..2 in.
Mounting plate	$2\frac{7}{8}$ in. diameter
Mounting holes (fit NACA optical recording base)	4 holes equally spaced on $2\frac{3}{4}$ in. diameter (clearance for 2-64 screws)
Weight	432 grams
Range with five mirrors (10 in. scale deflection)	30 in. Hg absolute
Diaphragm diameter	$2\frac{5}{32}$ in.
Diaphragm full-scale deflection	0.1 in.
Capsule volume with parts in place	1.42 in^3.

Accuracy

Hysteresis and friction	1/4%
Temperature effect	0.3%/100° F; zero shift

Acceleration effect at 40,000 ft
(at sea level, error is half this value):

Transverse (along axis of pressure stem)	0.1%/g
Vertical	0.2%/g
Longitudinal	0.2%/g

Reading accuracy .. .. 1 part in 1,000

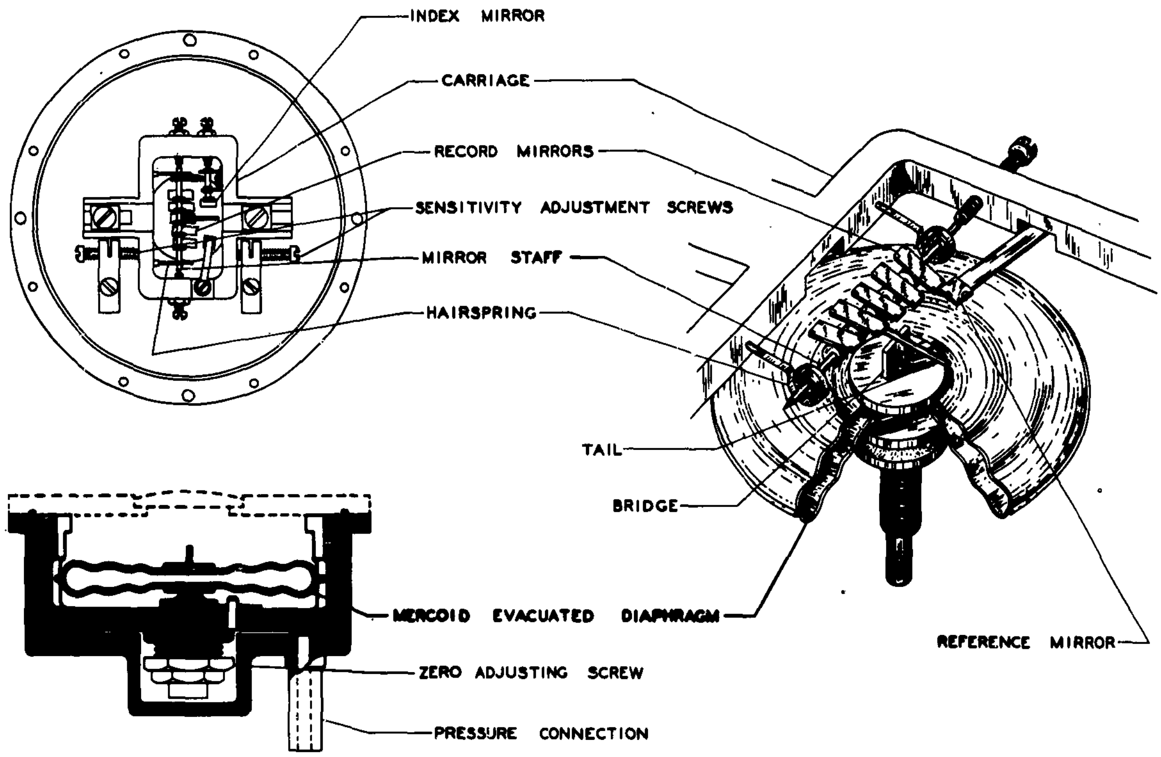


Figure D-1

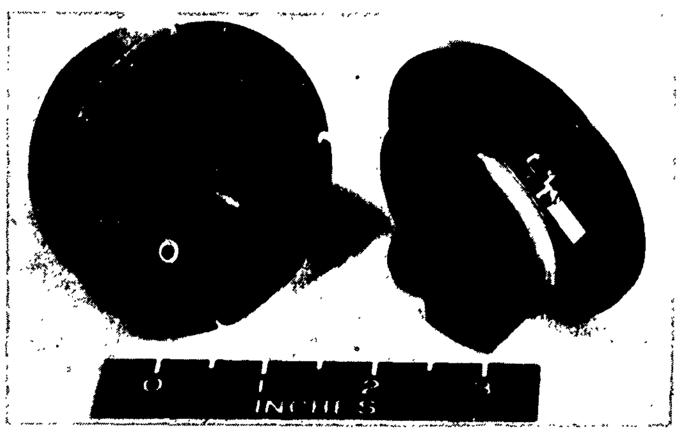


Figure D-2

APPENDIX E

Optical Recording Air-Damped Accelerometer

Principle of Operation

The NACA air-damped accelerometer consists of a brass cantilever vane, mechanically aged, which moves in an enclosing chamber so that its motions are air damped (Fig. E-1). A lens fastened to the vane adjacent to its free end deflects the image of a lamp filament onto a recording film so that displacements of the image on the film correspond to the acceleration forces acting on the vane. Damping adjustments are secured by varying the clearance between vane and chamber. Range and frequency adjustments are secured by using vanes of appropriate thickness, the acceleration ranges obtainable depending upon the permissible vane frequency for the desired application. Normally the range of usable frequencies extends from approximately 8 c/s to 25 c/s and the acceleration range from 2g to 12g full scale. Higher frequency vanes cannot be used because of the difficulty encountered in adequately damping them. A photograph of NACA air-damped accelerometers mounted in a standard base is shown in Figure E-2.

Description

Size (including 50 ft drum):
- 1 component, 15 in. by $5\frac{5}{8}$ by $6\frac{5}{8}$ in.
- 2 component, $12\frac{3}{4}$ in. by $7\frac{1}{8}$ in. by $6\frac{5}{8}$ in

Weight:
- 1 component, 11 lb 7 oz.
- 3 component, 12 lb 13 oz.

Range: 2g full scale to 12g full scale

Full-scale deflection:
- 1 in. for transverse and longitudinal elements
- 2 in. for vertical elements

Power requirements: (a) 400 cycle: 110V, 1/8 A

Accuracy

Recording: ±1/4% of full scale (±0.005 in. film deflection) on vertical element, ±1/2% on longitudinal and transverse elements.

(Figures E-1 and E-2 overleaf)

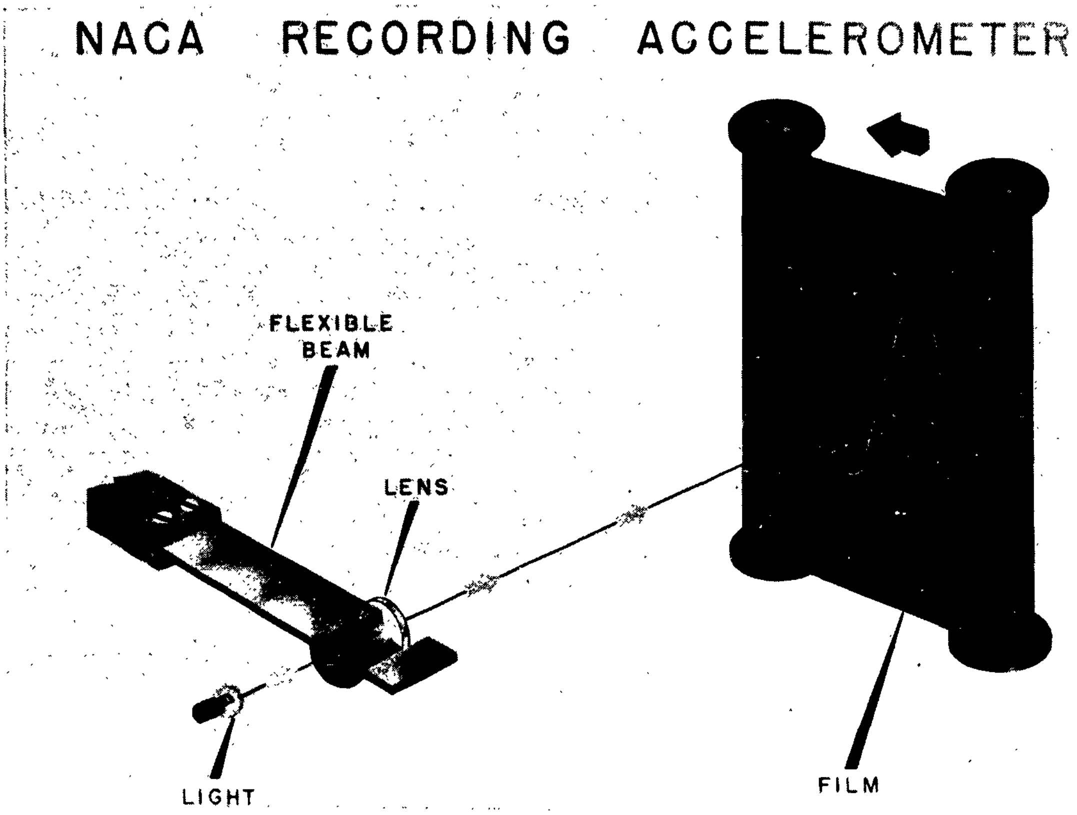


Figure E-1

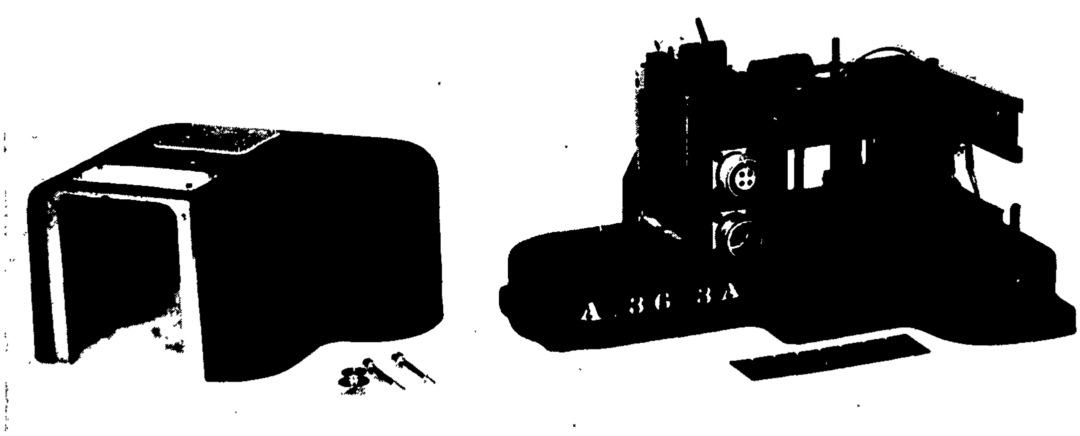


Figure E-2

APPENDIX F

Turnmeter, Type 44A

Principle of Operation

The turnmeter, photographs of which are shown in Figures F-1 and F-2, consists of a gyro driven by an electric motor. The motor is either an electrically governed d.c. type rotating at 5000 rpm or a synchronous 400-cycle motor rotating at 8,000 rpm. The gyro is restrained about one axis by a torque rod so that precessional torques acting on the gyro are opposed by the spring torque of the rod. Gyro deflections are therefore proportional to rate of turn about an axis perpendicular to the plane of the gimbal ring. The gyro and gimbals in most turnmeters of this type are similar and sensitivity to rates of turn is adjusted by inserting torque rods of various spring constants. A mirror fastened to the gimbal ring deflects an image of a lamp filament onto the recording film.

The gyro gimbal is coupled through a friction link to a freely pivoted inertia-damping wheel. This wheel provides damping and also compensation for angular accelerations about the torque-rod axis.

A revolution counter is fitted to the gyro motor which marks the film for each 25 revolutions of the gyro. The counter is used in conjunction with timer marks on the film to determine gyro speed.

Description

Size: $8\frac{1}{2}$ in. by $7\frac{1}{2}$ in. by $10\frac{1}{2}$ in.

Weight: 14 lb

Power supply: Units available with gyro motor supply 12 volts and 24 volts d.c., and 110 volts, 400-cycle a.c. Film drum motor supply 12 volts; 24 volts d.c. and 110 volts, 400-cycle a.c. Any combination of gyro and film motor supply can be used.

Full-scale deflection: 2 in.

Range: ±0.3 to ±3.5 rad/sec

Frequency: 10 to 25 c/s

Recording: Optical, $2\frac{7}{16}$ in. wide film

Wiring diagram: Assembly drawing number.

Accuracy

The accuracy of the Model 44 turnmeter for static measurements under flight conditions is within 1% $\pm 1\frac{1}{2}$ % per 100° F variation from calibration temperature if the gyro counter is employed with an accurate timer. It the gyro counter is not used, an additional 3% error may be caused by variations in gyro speed.

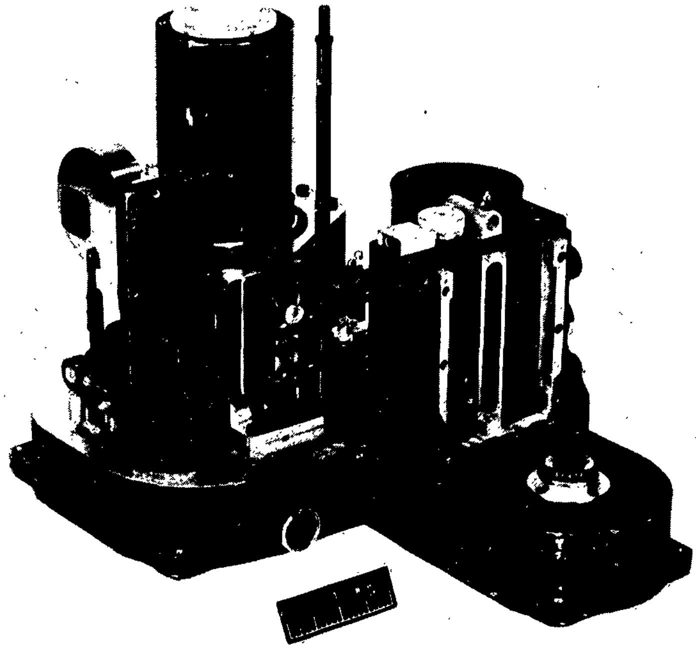


Figure F-1

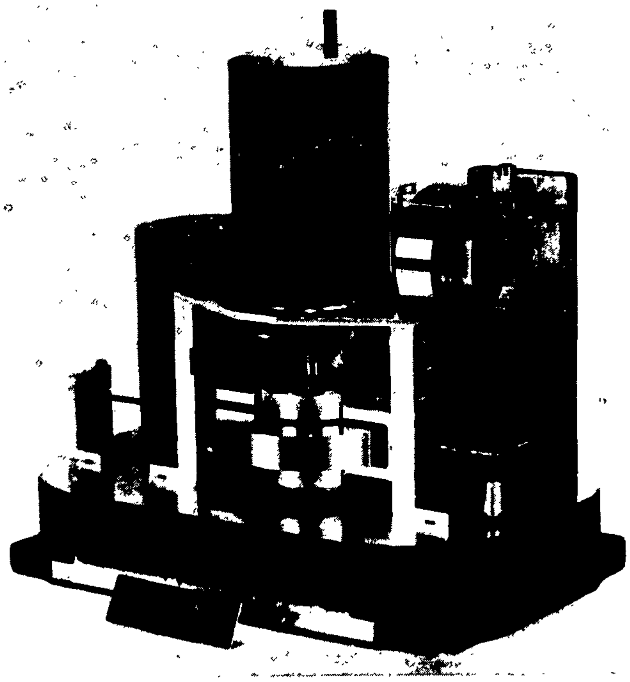


Figure F-2

APPENDIX G

Magnetically Damped 400-Cycle Angular-Velocity Recorder

Principle of Operation

The operation of the instrument, shown in Figures G-1 and G-2, depends upon the precessional force of a restrained gyro motor. The sensitive axis of the instrument is perpendicular both to the axis of rotation of the gyro motor and the axis of rotation of the gimbal ring.

The gyroscopic element in this recorder is the rotor of a 110-volt 400-cycle motor. This motor is rigidly mounted in a gimbal ring which is pivoted in precision ball pivot bearings.

The gyroscopic system is restrained by two springs made of a constant modulus material. The moving system is damped by an aluminum disk rotating in a magnetic field. The linkage shown in Figure G-2 amplifies the motion of the gyro gimbal to give the disk sufficient angular velocity to obtain the damping force required. The damping coefficient can be changed as desired by adjusting the air gap between pole faces of the magnets.

The optical system shown in Figure G-1 amplifies the motion of the gyro gimbal, and records this motion on film. This magnification is adjustable so that the sensitivity of the instrument may be varied.

Description

Size, including the 50 ft film drum: 14 in. long, 7 in. high, 7 in. wide

Full-scale deflection: ±1 in. on the film

Weight, including the 50 ft film drum: 16 lb

Power requirements: 110-volt, 400-cycle for both the instrument base bracket and the gyro motor

Range: 0.1 to 3 rad/sec

Natural frequency: $5 - 7\frac{1}{2} - 10 - 13\frac{1}{2}$

Damping: 0.65 of critical

Timing is as provided in the standard 400-cycle instrumentation.

Accuracy

A. Accuracy under standard laboratory condition (Note: All percentages are based on 2 in. full-scale film deflections):

1. Reading accuracy is ±0.5% (±0.01 in. on film)

2. Hysteresis and friction: ±0.5% maximum

3. Zero stability: ±0.5%

4. Gyro speed: synchronous with power supply

B. Corrections for deviations from standard conditions:

1. Temperature (135° F to - 30° F):

(a) Zero stability: no effect

(b) Damping is about 0.6 of critical at 135° F and is critically damped at -30°F as shown by calibration curve number 2

(c) Sensitivity: no change

2. Acceleration (up to 10g): ±0.5%

3. Alinement of axes: misalinement of the instrument about the axes of measurement will cause 0.5% error for 4° misalinement

4. Gyro speed: The gyro motor speed is synchronous with 400-cycle power. Thus any change in gyro speed, from the time of calibration, is initiated at the power supply and is not a fault of the gyro motor.

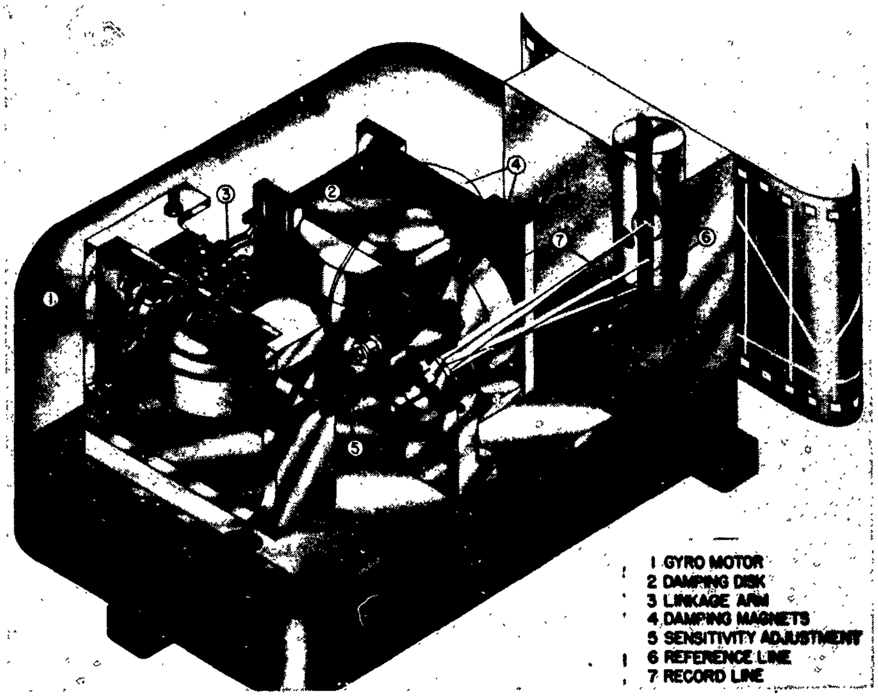


Figure G-1

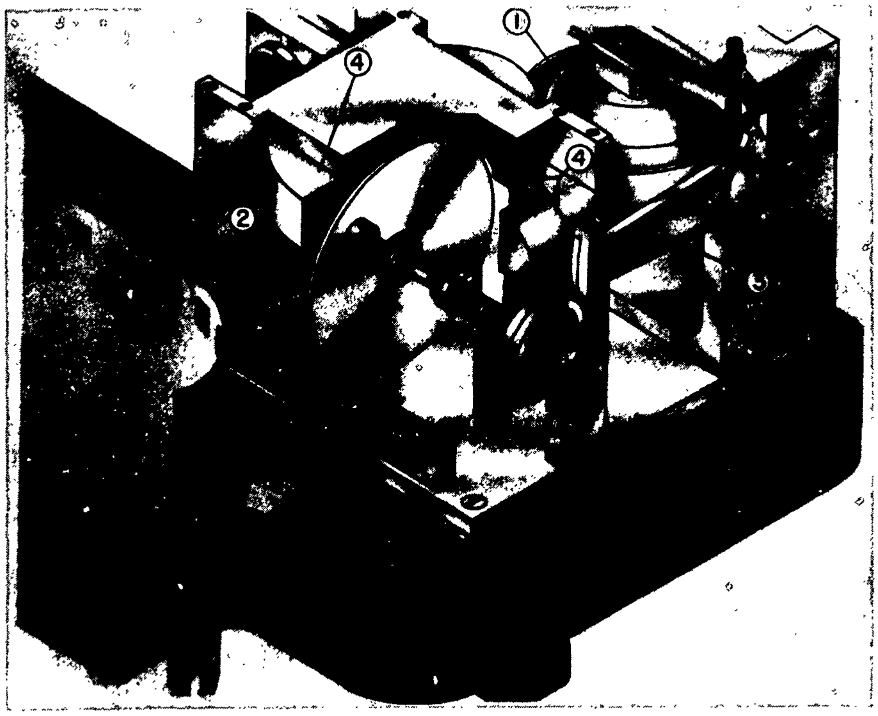


Figure G-2

APPENDIX H

Liquid-Damped 24-Volt D.C. Angular Velocity Recorder

Principle of Operation

The operation of the instrument shown in Figure H-1 depends upon the precessional force of a restrained gyro motor. The sensitive axis of the instrument is perpendicular both to the axis of rotation of the gyro motor and to the axis of rotation of the gimbal ring.

The gyroscopic element in this recorder is the rotor of a 24-volt d.c. gyro motor. This motor is rigidly mounted in a gimbal ring which is pivoted in precision ball pivot bearings.

The gyroscopic system is restrained by two extension springs made of a constant modulus material.

The moving system is damped by two bellows which also supply a portion of the restraining force. The linkage, shown in Figure H-1 (item number 3) was designed to reduce to a minimum the restraining force supplied by the bellows.

The two damping bellows are connected through a temperature controlled orifice shown in Figure H-2. A constant damping coefficient is obtained through the use of a bimetal strip to regulate the size of the orifice. This compensates for the change in viscosity of the damping oil caused by changes in temperature.

The damping can be varied as desired by moving the bellows assembly on the lever arm.

The optical system shown in Figure H-1 amplifies the motion of the gyro gimbal and records this motion on film. This optical system can be adjusted to change the optical magnification of the motion of the gyro gimbal in order to change the sensitivity of the instrument.

Description

Size, including the 50 ft film drum: $6\frac{1}{2}$ in. by 6 in. by 14 in.

Weight, including the 50 ft film drum: $14\frac{1}{2}$ lb

Full-scale deflection: ± 1 in. on the film

Power requirements:

(a) 400-cycle, 110 volts for the instrument base bracket
(b) 24 volts d.c. for the gyro motor

Gyro speed: Can be adjusted from 3,300 rpm to 7,000 rpm

Range: ± 1 rad/sec to ± 4.5 rad/sec

Natural frequency: 10 and 13.5 c/s

Damping: 0.65 of critical

Timing is as provided in standard 400-cycle instrumentation.

Accuracy

A. Accuracy under standard laboratory conditions:

1. Hysteresis and friction: ±1% maximum

2. Zero stability: ±0.5%

3. Reading accuracy: ±0.5%

Note: All percentages are based on 2 in. full scale film deflection.

B. Corrections for deviations from standard conditions:

1. Temperature (135° F to -30° F):

    (a) Zero stability: ±0.5%

    (b) Gyro speed: ±0.25%

    (c) Damping is between 0.55 and 0.7 of critical from 135° F to -20° F and 0.7 of critical from -20° F to -40° F as shown by graph number 4

2. Acceleration: ±0.5% maximum at 10g.

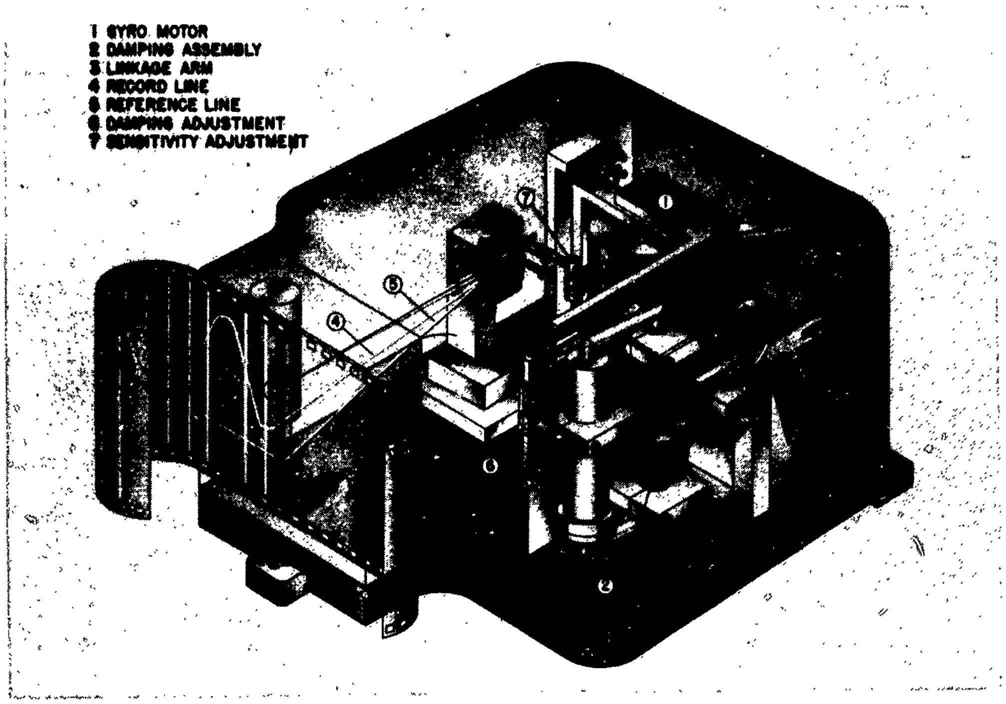


Figure H-1

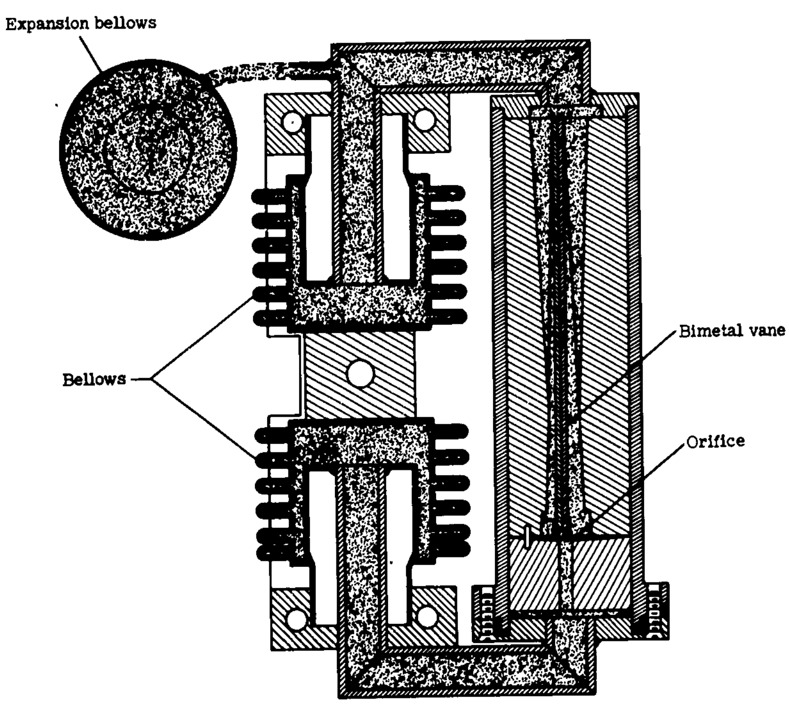


Figure H-2

APPENDIX I

Linear and Circular Control-Position Transmitters

Principle of Operation

The electrical circuit in the two control-position transmitters is a Wheatstone bridge circuit with two arms variable. Any variation in the resistance of the arms will unbalance the circuit and cause current flow to the recording galvanometer (see Figure I-1). The linear control-position transmitter is described; however, the circular transmitter is electrically identical (see Figure I-2).

The transmitter bridge circuit is made of 0.010-diameter Radiohm resistance wire mounted in a loop around a Bakelite mounting block. Power and galvanometer leads are connected to this loop as shown in Figure I-1.

The sliding contactor changes the ratio of resistance in two arms of the bridge circuit. In the linear unit, the sliding contactor is guided by two parallel rods on which are mounted two compression springs to remove backlash from the string-actuated slider. In the circular unit, the sliding contactor is rotated by means of a shaft protruding from the bottom of the unit.

A control box is equipped to handle three control-position transmitters. In each circuit in the control box is a ballast tube which keeps the voltage input to the bridge circuit constant, and a selector switch which changes the series resistance to the galvanometer in order to change the sensitivity of the unit.

Description

Size: Linear transmitter, 8 in. by $1\frac{3}{4}$ in. by $\frac{5}{8}$ in.

Circular transmitter, $1\frac{1}{2}$ in. diameter, $1\frac{3}{4}$ in. long

Control box (three-channel), $6\frac{1}{4}$ in. by $4\frac{5}{8}$ in. by $3\frac{1}{16}$ in.

Weight: Linear transmitter, $\frac{1}{3}$ lb

Circular transmitter, $\frac{1}{10}$ lb

Control box, $2\frac{1}{2}$ lb

Range, maximum: Linear transmitter 4 in. travel maximum, minimum travel approximately $\frac{3}{4}$ in., depending on galvanometer

Circular transmitter, maximum 350° rotation, minimum 100° rotation

Power required to the control box: 12 volts d.c. With the addition of a 50 ohm resistor in series with the power supply, 24 volts d.c. can be used.

Accuracy

A. Accuracy under standard laboratory conditions:

1. Hysteresis: none

2. Zero stability: no zero shift

3. Sensitivity: The change in sensitivity is approximately 0.2% per volt change in the power supply between 11 and 13 volts.

4. The force necessary to operate the linear unit varies from $\frac{1}{2}$ lb at one end to 2 lb at the other end of slider travel.

5. The force necessary to operate the circular unit is approximately 0.1 oz. in. torque.

B. Correction for deviations from standard conditions:

1. Temperature: none

2. Accelerations: none

3. Vibrations: none

C. Dynamic errors:

1. Under standard or flight conditions, the linear and circular control-position transmitter will operate to at least 50 in./sec.

The accuracies listed are additive with the errors of the recording galvanometer.

Installation Instructions for Both Units

A. The transmitter should be mounted firmly to the control surface.

B. Any knots tied in the connecting string should be very tight and shellacked.

C. If the connecting string is not parallel to the air flow, a shield should be placed over the unit.

D. Before and after flight, a zero check should be made to detect any zero shift in the transmitter and attached galvanometer.

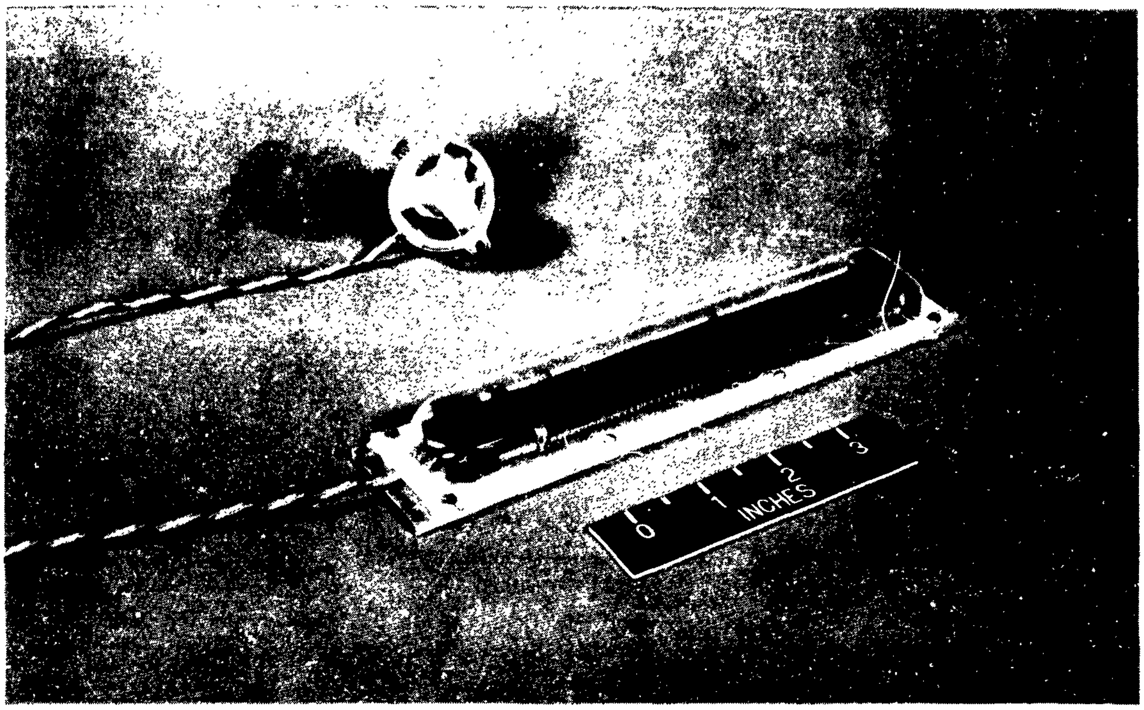
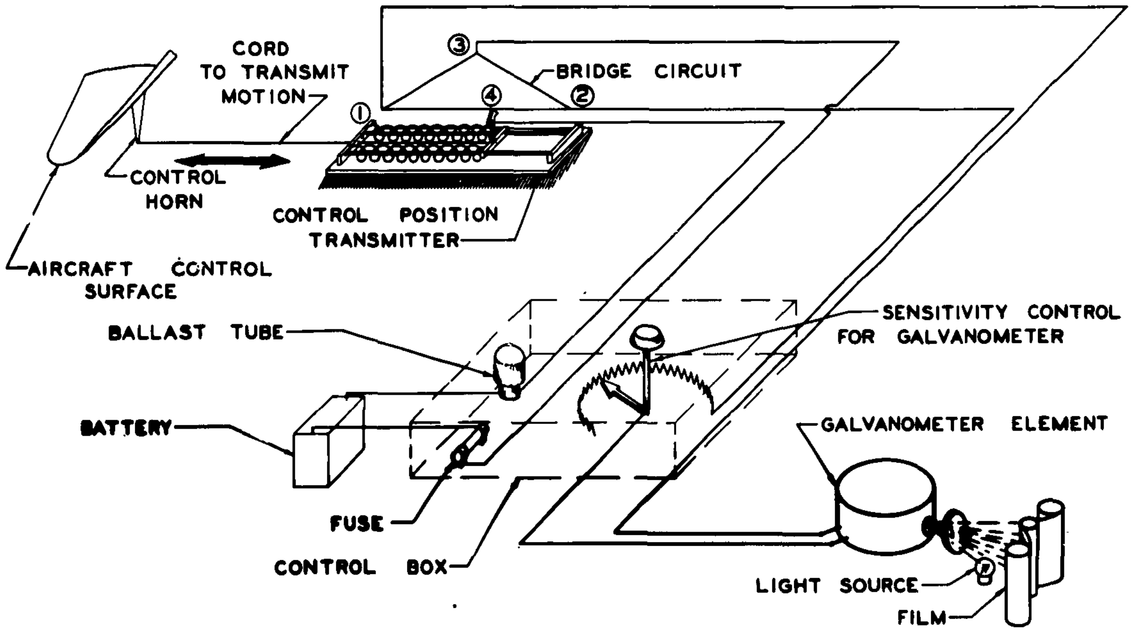


Figure I-1



CONTROL POSITION RECORDER

Figure I-2

APPENDIX J

Flow-Direction Recorder

Principle of Operation

The flow-direction instruments (Figs. J-1 and J-2) make use of autosyn systems. Autosyns are synchronous devices in which the receiver follows the rotation of a remote, mechanically turned, transmitter. Torque is transmitted electrically between the transmitter and receiver. A flow-positioned vane turns the transmitter. The autosyn receiver is mounted in a recording base as shown in Figure J-3 and has mirrors attached to its shaft which reflect light beams to the film according to the rotation of the shaft.

The counterbalanced, freely-turning vane is alined with the air stream by action of the air on the vane. When the transmitter is oriented to measure yaw, the vane extends vertically from the boom. For measurement of angle of attack, the boom is rotated 90° about the longitudinal axis of the instrument.

The model 45 yaw transmitter has the vane coupled directly to a transmitting autosyn, and turns through 360°. However, the flow-direction recorder limits the angle which may be measured to $\pm 40^{\circ}$.

The Pitot-static flow-direction boom is a combination flow-direction transmitter and Pitot head. The autosyn transmitter is positioned by the vane through a linkage system. Stops limit the swing of the vane to $\pm 15^{\circ}$. This rotation is magnified by the two-to-one ratio of the linkage, and the autosyn transmitter rotates $\pm 30^{\circ}$ in order to secure increased accuracy.

The flow-direction recorder contains the autosyn receiver which has four mirrors attached to its shaft. The mirror reflects the focused image of the source lamp filament to the film slit. Rotation of the autosyn shaft then produces deflections of the image on the film.

A transformer supplies 26-volt, 400-cycle, and 3-phase power to the autosyn system continuously. When taking a record, a relay within the recorder applies 55-volt, 400-cycle power to the autosyn system. The increased voltage gives higher torque to drive the receiver into the null position and therefore reduces the effect of friction in the receiver autosyn bearings.

The mirrors are arranged so that each mirror produces a record during 20° of shaft rotation. The four mirrors give 8 in. of record with 80° of shaft rotation. The standard 50 ft by $2\frac{7}{16}$ in. film drum is used. (See Appendix K.)

Accuracy

Reading accuracy: The film deflection record can be read to about 0.01 in. As 90° of receiver rotation corresponds to 8 in. of record deflection, the reading accuracy will be about 0.1°.

Hysteresis and friction: Hysteresis can be practically eliminated by very careful cleaning of the autosyn bearings. While a certain amount of friction hysteresis is present under static conditions, the vibration present in the airplane suffices to reduce such effect to no greater error than about 0.1° in the receiver.

Supply voltage: Since the autosyn is a null-reading instrument, ordinary voltage variations have negligible effect on the accuracy.

Temperature: The electrical characteristics of the autosyn system are not susceptible to temperature changes. The upper limit of allowable temperature would be governed by the insulation on the autosyn windings. The low-temperature limit would depend on the oil in the bearings. The bearings should contain only a very small amount of low-temperature coefficient oil.

Acceleration: The transmitter vane and recorder mirror unit are counterbalanced for elimination of acceleration effects.

Dynamic errors: The natural frequency of the autosyn is about 15 c/s with 55-volt excitation, and decreases with lowered voltage. The response is flat to about 3 c/s with 55 volts applied.

Installation

The recorder may be installed at any convenient location with shock mounting not usually required. Some vibration is desirable to minimize frictional errors, and shock mounting should be required only when the recorder is installed in locations subject to severe vibration.

The usual wing-tip installation has a boom of 1 in. steel tubing extending a minimum of one chord length in front of the leading edge to put the vane in air relatively undisturbed by the airplane. A wooden stiffener is taped along the bottom of the tube to dampen oscillations.

The Pitot-static head is usually mounted on the forward end of the fuselage on an adapter of sufficient length to place the vane a fuselage maximum diameter ahead of the nose if possible.

Field Check and Calibration

Although a performance calibration is made in the laboratory, the final calibration is made with the system installed in the airplane. The yaw transmitter is installed with the center line as nearly parallel as possible with the airplane center line. Then the true zero position of the vane is found with a transit, and this zero position is used as a reference in the final calibration.

Figure J-1

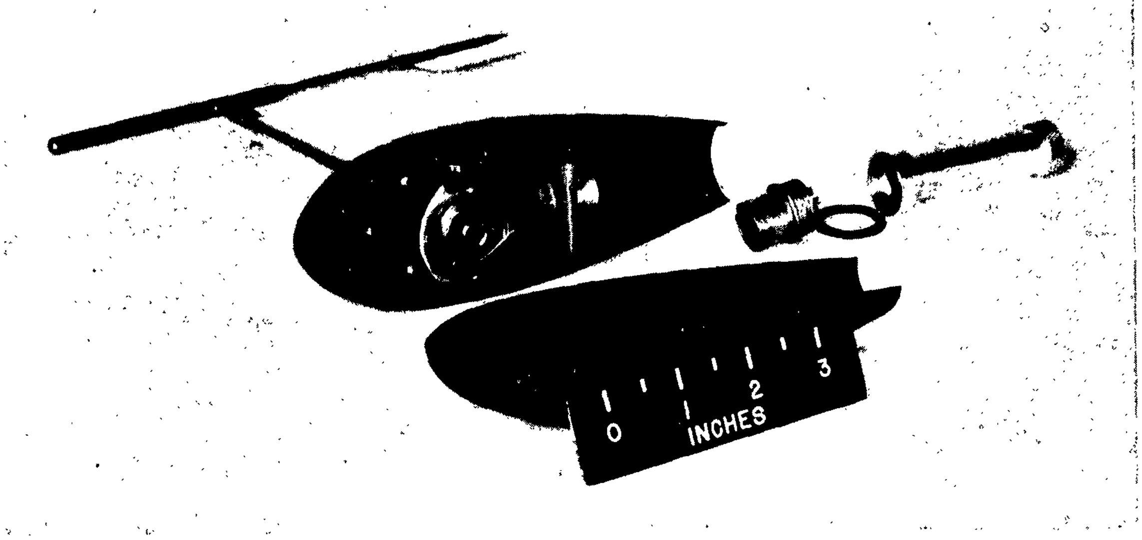


Figure J-2

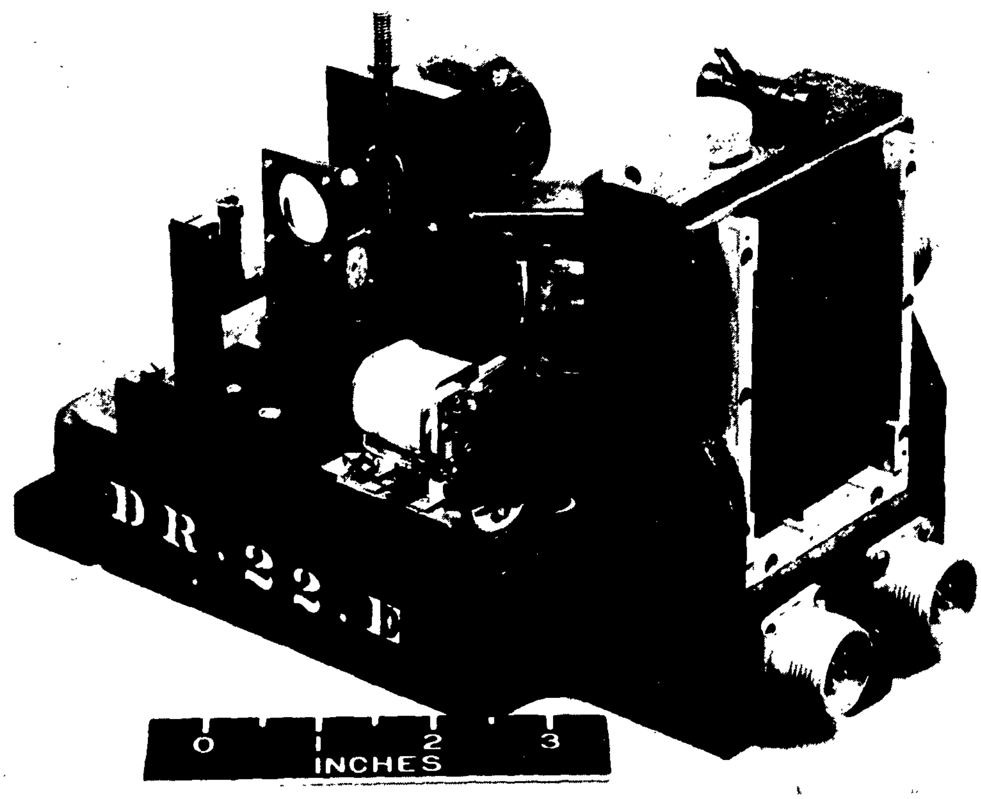


Figure J-3

APPENDIX K

Film Drums

Principle of Operation

Figures K-1 and K-2 show the operation and general arrangement of the film drums for use with the various recorders. The drums use a 400-cycle, 115V a.c., 3-phase, synchronous motor which turns at 8,000 rpm. The film speed range is based on the speed of this motor. In a few special cases a 12V d.c. motor operating at about 3,800 rpm may be used. In such cases, the noted film speeds should be corrected by multiplying the given speeds by the ratio of motor speeds. Film drums are made in several sizes. There is a $2\frac{7}{16}$ in., 20 ft and a $2\frac{7}{16}$ in., 50 ft drum; also, a $6\frac{1}{2}$ in. drum in 20- and 50- ft sizes.

The transmission in a drum consists of two worm-gear combinations. Interchangeable speed gears having single, double, triple, and quadruple leads are provided with each drum. Single lead gears are numbered (1), the double lead (2), etc. With the 400-cycle motor, the lowest film speed is $\frac{1}{4}$ in. per second using the (1) set of worm and gear in each position. Changing one set to the number (2) will double the speed to $\frac{1}{2}$ in. per second. In other words, the product of the gear numbers times $\frac{1}{4}$ will be the film speed in in./sec. Except for the lead, all worms and gears are identical, so they may be used in either position so long as the mating worm and gear have the same number. To obtain lower speeds, special transmissions inserted between the two worm and gear pairs have been built. These introduce 4 to 1 drop in speed. For higher speeds, pairs of spiral gears have been adapted to fit in place of the worm and gear at the drive roller. Since the replaced worm gear has 38 teeth, the first four speeds are multiplied by 38.

The maximum temperature range for the film drums is from -50° F to $+140^{\circ}$ F. At $+140^{\circ}$, the nitrate film begins to decompose and forms gas which limits the use of the drum to below this temperature. With the use of 'safety' film (acetate base), the limiting temperature may be increased to 250° F.

Installation

All 400-cycle drums are fitted with a face plate which fits into mating gibs on the instrument bracket and the drum is locked in position by a film drum lock located on the instrument bracket. The power chord to the drum is a three conductor rubber covered number 18 wire fitted with a four-prong A and N male connector. The connector is plugged into its mating receptacle on the instrument bracket (usually the topmost receptacle).

General Characteristics of Film Drums

Film size	*Size (in.)*	*Weight (loaded) (lb)*	*Power*
$2\frac{7}{16}$ in × 20 ft	$4\frac{3}{4} \times 4\frac{9}{16} \times 5\frac{1}{8}$	4.09	110V - 400 ~ -3ϕ
$2\frac{7}{16}$ in × 20 ft	$5\frac{5}{8} \times 5\frac{13}{16} \times 5\frac{1}{8}$	5.22	110V - 400 ~ -3ϕ
$6\frac{1}{2}$ in × 20 ft	$4\frac{3}{8} \times 4\frac{9}{16} \times 9\frac{1}{4}$	6.20	110V - 400 ~ -3ϕ
$6\frac{1}{2}$ in × 50 ft	$5\frac{5}{8} \times 5\frac{13}{16} \times 9\frac{1}{4}$	8.10	110V - 400 ~ -3ϕ

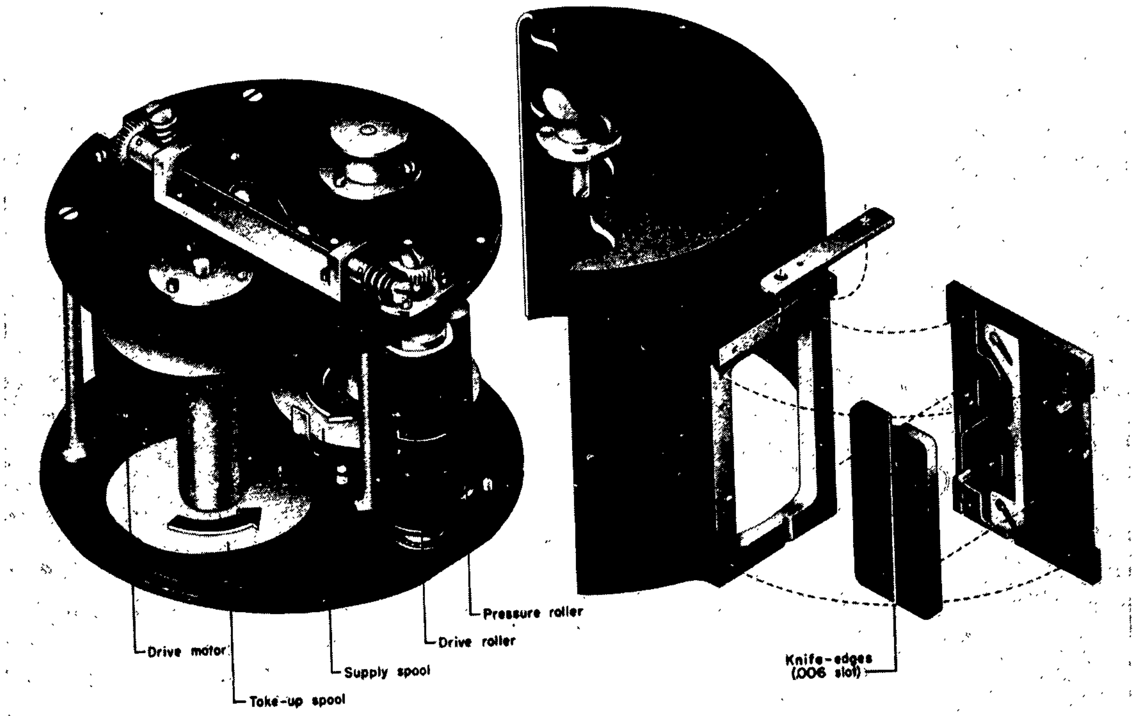


Figure K-1

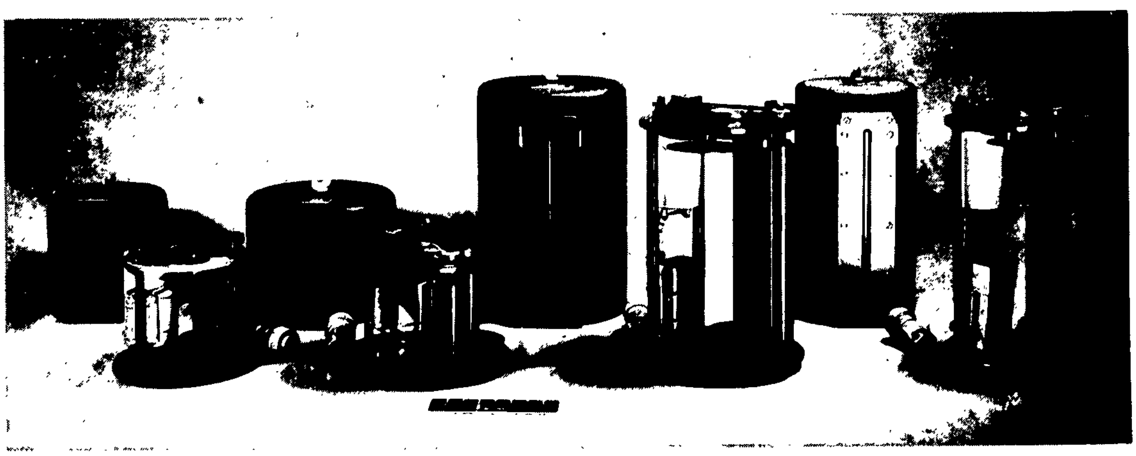


Figure K-2

APPENDIX L

Optical Recording Magnetically Damped Accelerometer

Principle of Operation

Each acceleration sensing element consists of a small beam on a pivot shaft running in jewel bearings. The beam motion restraining force is supplied by a small pair of opposed helical springs. A mirror mounted on the pivot shaft is arranged to reflect the focused image of a lamp filament onto the film in the film drum. Thus, as the beam is rotated through a small angle by the force of acceleration, the recorded trace on the film moves across the film a proportionate amount. Eddy-current damping force is provided by a small aluminum vane fastened to the free end of the beam and situated in a strong magnetic field. The sensitivity and frequency are determined by the springs used. The natural frequency is approximately ten times the square root of the range in g for 2 in. film deflection.

Units have been set up ranging from 1g for 2 in. film travel with 10 c/s natural frequency to 14g for 2 in. film travel with 38 c/s natural frequency. The one-component instrument has been used principally as a longitudinal accelerometer for drag determination. For this application two data mirrors are used, each covering two inches of film travel, with a range of ±1g for ±2 in. film travel.

Figure L-1 shows a photograph of the one-component recorder and Figure L-2 shows a photograph of the three-component recorder.

Description

Size (including 50 ft drum): $\left\{\begin{array}{l}\text{1 component, 15 in. by 8 in. by } 6\frac{11}{16} \text{ in.}\\ \text{3 component, } 13\frac{7}{8} \text{ by } 5\frac{3}{4} \text{ by } 6\frac{1}{4} \text{ in.}\end{array}\right.$

Weight: $\left\{\begin{array}{l}\text{1 component, 12 lb}\\ \text{3 component, 15 lb}\end{array}\right.$

Range: 1g to 14g full scale

Full-scale deflection: $\left\{\begin{array}{l}\text{1 component, 2 in. per mirror}\\ \text{3 component, 2 in. for normal, 1 in. for transverse and longitudinal}\end{array}\right.$

Power requirements: 110 volts, 400 cycle, 3 phase

Accuracy

Accuracy under standard laboratory conditions:

Hysteresis and friction: The stresses in the spring material used are low enough that there is no measurable hysteresis. The effect of friction is generally less than 0.01g. Since the beam mass and pivot configuration are the same for all ranges, friction

effects appear more as an increment of g than as a percentage of full scale. Presuming a record reading accuracy of 0.005 in., the over-all accuracy then tends to be limited by friction for sensitivities greater than 0.5 in. per g and by reading accuracy for lower sensitivities.

Stability of zero and sensitivity: No changes of zero or sensitivity greater than 0.5% of full scale have been noted over several months time.

Dynamic errors:

Response: Since the damping forces are linear, the response of the instrument agrees with the theoretically predicted response of a single-degree-of-freedom system. Normally the damping is adjusted to 66% of critical so the response is flat within 2% up to about 65% of the natural frequency.

Lag: The lag is the theoretical lag predicted for a single-degree-of-freedom system having linear damping. With the percentage of critical damping used, the lag will vary about linearly from 0° to 90° as the impressed frequency varies from 0 to the natural frequency.

Installation instructions and precautions:

The accelerometer, when used to measure airplane flight-path accelerations, should be installed as close as possible to the c.g. of the airplane. The instrument should be solidly fastened on a rigid mounting attached to the primary structure of the airplane to avoid pickup of extraneous vibratory accelerations.

The three-component instrument should be accurately aligned with the three primary axes of the airplane. Calibrations are furnished on the basis that the instrument is mounted based down the with film drum aft in the airplane.

If the instrument is mounted away from the c.g. of the airplane, centrifugal accelerations due to angular velocity and linear accelerations due to angular acceleration will be impressed on the elements.

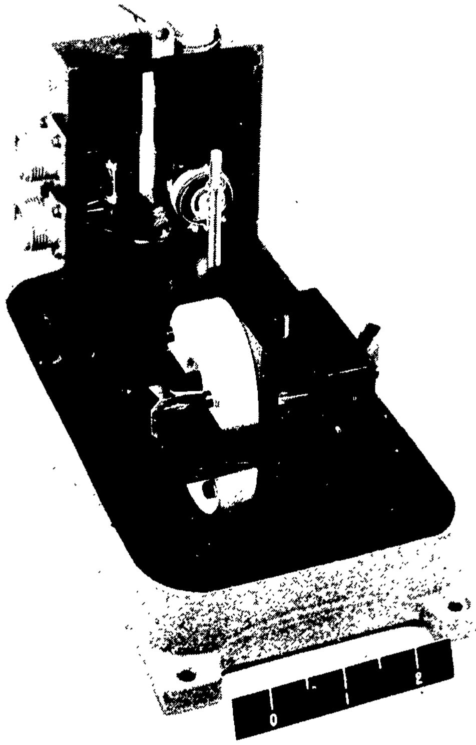


Figure L-1

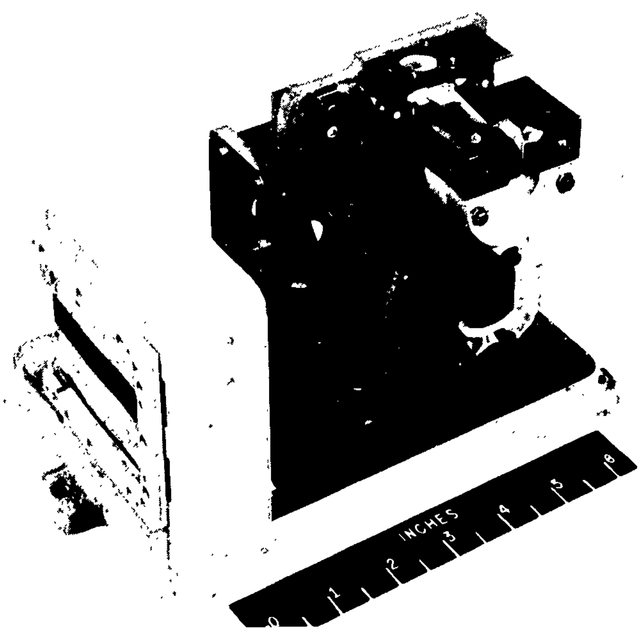


Figure L-2

APPENDIX M

Recording Tachometer

Principle of Operation

A three-phase alternating-current generator is driven by the motor whose speed is to be measured. Current from this generator drives a synchronous motor in the recorder at a speed proportional to the speed of the generator. Permanent magnets are mounted in two circular rows on the end of the motor shaft with an aluminum drag disk mounted on a separate shaft between the magnet poles. The magnetic field produced by the rotating magnets causes eddy currents which tend to pull the disk in the direction of rotation. The disk shaft is spring restrained so that angular displacement of this shaft is proportional to the speed of rotation of the magnets. The angular position of the shaft is recorded by means of three mirrors which are mounted on the tachometer shaft at an angle to one another such that the images will be formed two inches apart on the film.

Transparent plastic wedges are used to provide means of identifying the image formed by each mirror. The wedges are clamped to the lens and partially cover two of the mirrors. Light passing through the wedge is refracted and forms an image on the film near the one formed by the mirror alone. Therefore a pair of lines is recorded for each mirror equipped with a wedge, the distance between them depending on the angle of the wedge. This arrangement causes the record lines to appear as follows: (1) lines with tracer spaced 0.03 in., (2) line with no tracer, and (3) line with tracer spaced 0.06 in. A typical calibration curve is shown in Figure M-1.

The spring constant of the restraining spring and the resistivity of the drag disk vary with temperature, causing the tachometer to change sensitivity with temperature. The reference mirror is mounted on a bimetal strip in such manner that the effective instrument zero is changed to minimize the effects of change in temperature.

The moving system is damped by means of a thin film of high viscosity damping fluid between the tachometer front plate and a small disk on the drag disk shaft. Damping is employed to prevent high-frequency oscillation of the drag disk shaft rather than to obtain proper dynamic response and is more effective when the damping ratio is somewhat higher than critical.

Description

Size (including 50 ft film drum): $\left\{ \begin{array}{l} 12\frac{3}{8} \text{ in. long, 8 in. wide,} \\ 6\frac{5}{8} \text{ in. high} \end{array} \right.$

Weight(including 50 ft film drum): 10 lb

Range: The maximum shaft speed which can be measured is 5,000 rpm. The tachometer is normally adjusted to record approximately 30% of the full-scale speed range, but this recording interval can be varied from 12% to 40%. The minimum shaft speed which can be measured is 200 rpm.

Film deflection: Total deflection 6 in., 2 in. for each of three mirrors

Power requirements:
1. 400 cycle, 110 volts, three-phase for the instrument base bracket
2. Three-phase power from the tachometer generator for the tachometer motor

Damping: Approximately twice critical

Timing: As provided in standard 400-cycle instrumentation.

Accuracy

Accuracy under standard laboratory conditions:

1. Reading accuracy: ±0.01 in. film deflection
2. Hysteresis and friction: ±0.1% of full scale
3. Supply voltage variations: Negligible, provided the tachometer generator voltage is high enough to start the motor

Corrections for deviations from standard conditions:

1. Temperature: ±0.2% for 100° F change
2. Linear acceleration: ±0.1% of full scale for ±1g in any axes
3. Vibration: No effect, except to make it difficult to read film deflection accurately

Installation, Instructions, and Precautions

The tachometer motor requires a few seconds to reach operating speed and therefore should be running about a minute before any records are taken. The tachometer is usually wired directly to the tachometer generator so that it runs whenever the aircraft engine is running.

The tachometer motor will run backwards and no records will be obtained if the phase relation of the generator current is wrong. For proper operation, the recorder should be wired in parallel with the indicating tachometer and should be checked before flight.

Voltage output of the tachometer generator must be enough to start the recording tachometer and the indicating tachometer on the aircraft instrument panel. This voltage should be measured with both motors in the circuit and running. The following values will insure safisfactory operation:

Generator shaft speed (rmp)		EMF (volts)
4 pole	2 pole	
500	1,000	4.9
1,750	3,500	15.5
2,000	4,000	17.0

If the voltage is less than these values, the tachometer generator must be replaced with one containing a stronger magnet.

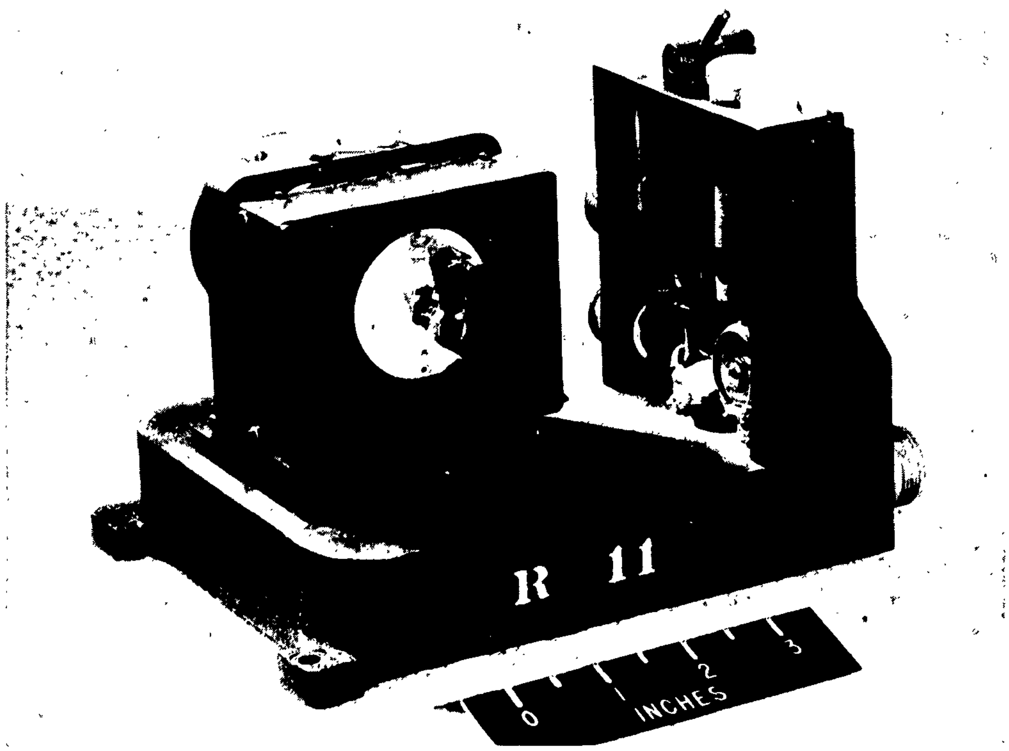


Figure M-1

APPENDIX N

16 MM 'Filmo' Photo Data Recorder

Principle of Operation

The operation of the instrument is the conventional shuttle pull-down mechanism which is synchronized with a rotating disk shutter. Two sprockets drive the feed and take up film loops on either side of the gate. The takeup spool is driven by a slip clutch spindle geared from the main power unput shaft. Framing speed changes are accomplished by the interchanging of the worm and worm gear pairs at the motor shaft. Framing speeds are controlled by the 400-cycle synchronous motor which is powered by a governed 400-cycle inverter.

There is no heater built in the camera; however, this could be done in cases where necessary.

Description

Size (including lens): $4\frac{3}{8}$ in by $6\frac{7}{8}$ in by $8\frac{1}{2}$ in

Weight (including 100 ft spool): 5 lb 8 oz

Range:

1. Framing speeds: 16, 24, 33, 66, and 133 frames/sec
2. Optical focus: $1\frac{1}{2}$ ft to ∞
3. Film capacity: 100 ft spool, daylight loading (black and white or color)

Power requirements:

1. Induction Motors Corporation: 400-cycle, 3-phase, 8,000-rpm motor; 115 volts, 0.3 amp to 1.75 amp
2. Delco series motor: 5,000 rpm, 28 volts d.c., 1.75 amp

Timing: Timing is provided by two neon T-2 glow lamps arranged so that one projects a spot on the lower edge of the film, and the other a spot on the top edge. These lamps are operated from the standard instrument timer.

Accuracy

Reading accuracy: In most cases, the resolving power of the film and lens combined will enable the negative to be read to 0.001 in. or less. If greater accuracy is required to obtain satisfactory results, longer focal length lenses, larger negative size, or a combination of both must be substituted.

Frame registration: These cameras will locate each frame, along the length of the film, with a maximum displacement of 0.002 in. Since most readup techniques require measurement to 0.001 in. or less, the registration errors must be eliminated by taking measurements from the frame edges, rather than perforations or film edges.

Supply voltage variations: The cameras are not affected by voltage variations once they are 'locked in' at synchronous speed until the voltage drops below 100 volts, approximately. (This figure will vary, depending upon the load.) Low voltages at start may cause the motor to run below synchronous speed; again, this will depend upon the load and the actual value of the supply voltage.

Temperature effects: The cameras will operate reliably at temperatures from $+150^{\circ}$ F to -40° F. At the colder temperatures and high framing speeds, however, the camera motors may run a few rpm under synchronous speed. The exact amount will vary depending on the total camera load at the time of the run. This lag may be found by checking the number of frames taken between the timing marks on the film's edge.

Acceleration and vibration effects: The camera will operate satisfactorily at accelerations up to 6g. Vibrations of 1/32 in. double amplitude, 0-06 c/s make no apparent changes in camera performance.

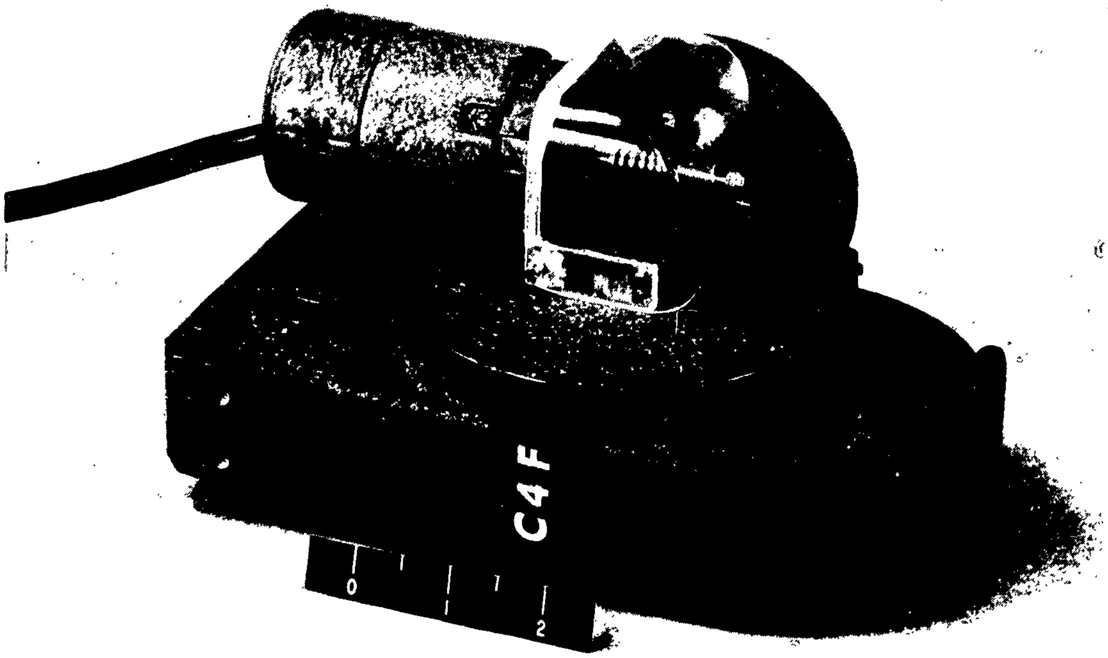


Figure N-1

APPENDIX O

16 MM GSAP Photo Data Recorder

Principle of Operation

The operation of the instrument is conventional, that is, a shuttle pull down is synchronized with a rotating disk shutter. A sprocket film drive inside the magazine supplies the film to the gate and also operates, through a series of gears, the takeup spindle. Temperature control is maintained by a Stevens Thermo switch which makes and breaks continuous 28V d.c. power to a resistance type, glass-covered heater wire. A mechanical fly ball governor operates a spring loaded set of points which open and close the motor circuit to maintain the proper framing speed.

Description

Size (including lens): $2\frac{1}{2}$ in by $3\frac{1}{2}$ in by 7 in

Weight (including full 50 ft magazine): 3 lb

Range: 1. Framing speeds: 1/2, 1, 2, 8, 16, 32, and 64 frames/sec

2. Optical focus: $2\frac{1}{2}$ ft (by addition of spacers) to ∞

3. Film capacity: 50 ft magazine only

Power requirements: 28 volts

1. Motor current: Bell and Howell, 1.0 amp, 250 rpm Delco, 0.15 amp

2. Heater current: 1.75 amp

Film speeds: 1. 1/2, 1, and 2 frames/sec - Delco Motor, 250 rpm

2. 16 and 32 frames/sec - Bell and Howell Motor, 3,840 rpm

3. 32 and 64 frames/sec - Bell and Howell Motor, 7,680 rpm

Timing: Timing pips are provided by a V-3 microswitch which is closed at the instant of shutter opening.

Accuracy

Reading accuracy: In most cases, the resolving power of the film and lens combined will enable the negative to be read to 0.001 in. or less. If greater accuracy is required to obtain satisfactory results, longer focal length lenses, larger negative size, or a combination of both must be substituted.

Frame registration: These cameras will locate each frame with a maximum displacement of 0.002 in. Since most readup techniques require measurement to 0.001 in. or less, the registration errors must be eliminated by taking measurements from frame edges, rather than perforations or film edges.

Supply voltage variations: The cameras are regulated to operate at a constant speed through governor control from 21 to 29 volts.

Temperature effects: The cameras will operate reliably at temperatures from +150° F to -40° F.

Acceleration and vibration effects: The camera will operate satisfactorily at accelerations up to 6g. Vibrations of 1/32 in. double amplitude, 0-06 c/s make no apparent changes in camera performance.

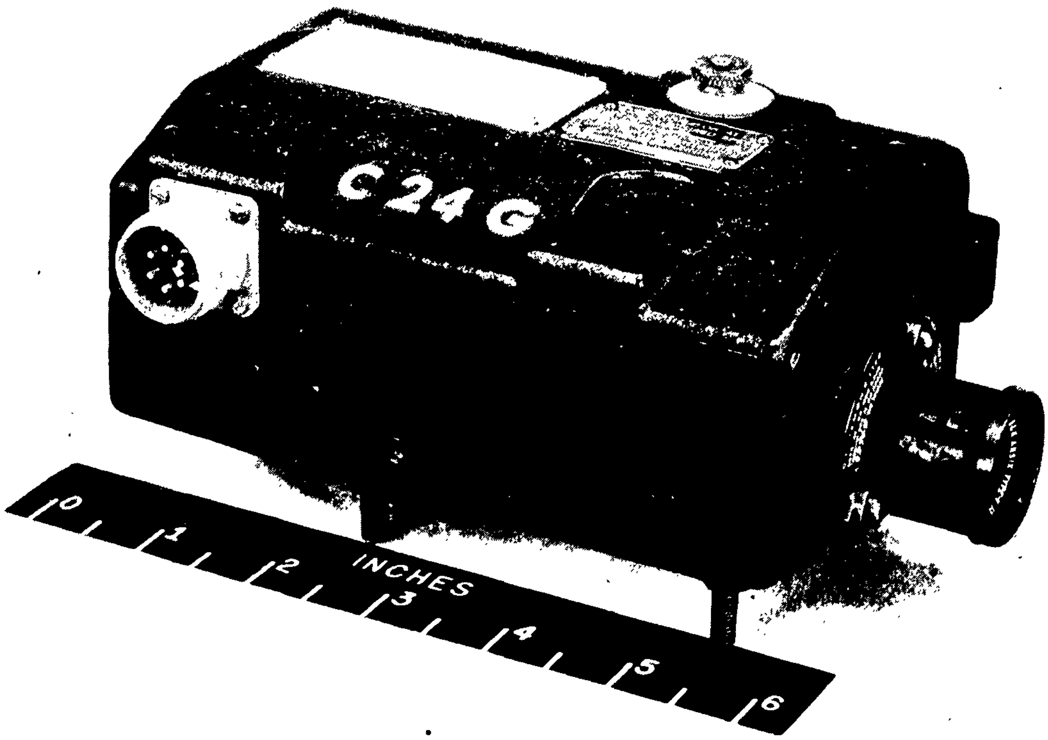


Figure 0-1

APPENDIX P

Strain-Gage Control Box Model 50C

Principle of Operation

The control box provides facilities for interconnecting strain-gage bridges, strain-gage power, and recording or indicating instruments. Balancing potentiometers are provided for changing the zero-strain output of each channel. Series resistors may be connected to reduce the voltage to each channel for bridges which must operate at values lower than that supplied to the control box. By means of the remote control circuit, operating a motor-driven nonshorting switch, a calibrate resistor is momentarily connected to each strain-gage bridge.

The complete calibrate cycle, one revolution of the switch, requires $1\frac{1}{2}$ sec when operated at 40 rpm. Correspondingly the dwell time is 1/8 sec for each channel, with a 1/16 sec interval between each period of dwell. Speeds slightly less than 40 rpm may be obtained by adjusting the resistor in the motor circuit. This resistor is normally shorted so that the motor operates at full voltage.

The calibrate cycle is initiated by momentarily applying +28 volts to pin 'K' of the 9-pin remote control receptacle. During the interval that channel 18 is connected to the calibrate resistor, a positive 28-volt pulse is supplied at pins 'D' and 'E' of the remote control receptacle. This pulse may be used to operate calibrate relays. The next succeeding interval provides a similar pulse to pins 'F' and 'H' which may be used to operate a remote power-off relay. Such a power-off relay is desirable for determining galvanometer zeros. If more than one control box is used in a given installation, use the box with the lowest motor speed to operate the power-off relay for power to all the control boxes. At the completion of the calibrate cycle the motor is braked to stop. The remote control circuit is then ready for the next cycle. A pilot light may be connected between pin 'K' and ships ground. Such a lamp will remain lit during 7/8 of the calibrate cycle, and provides a method by which the operator may know when the calibrate cycle is approximately complete.

The resistance calibration is made in groups of three channels at a time, in the following order:-

1,	7,	13
2,	8,	14
3,	9,	15
4,	10,	16
5,	11,	17
6,	12.	18

Where each column has an individual calibrate resistor, calibrate resistors may be obtained with 1/10% of the following values:-

25,000 ohm	200,000 ohm
50,000 ohm	400,000 ohm
100,000 ohm	500,000 ohm

The control-box outline is shown in NACA drawing No. LD-37388 and the circuit diagram in LC-37389. Figures P-1 and P-2 show external and internal views of WSG Control Box Serial No. 6. In other boxes there are variations in resistors and relays.

Description

Size: $5\frac{3}{4}$ in by $3\frac{3}{8}$ in by 16 in with connectors

Weight: 7 lb, ±3%

Range: 18 channels of strain gage or similar bridges

Power requirements:

1. Strain-gage power; separate battery at a potential, usually 24 volts, suitable for strain gages
2. 28 volts, d.c. for the remote control circuit, current drawn is approximately 200 milliamperes.

Installation, Instructions, and Precautions

Observe the required input polarities. Reversed bridge power input will result in reversed galvanometer deflections. Reversed remote control power will cause the calibrate motor to rotate in the wrong direction and leave calibrate resistors connected to channels 6, 12, and 18.

The control box may be mounted in any position by means of holes drilled, as desired, through the back or by brackets attached externally.

Field Checks

Proper operation may be determined by observing any record that includes a calibrate cycle, incidental to checking the complete strain-gage installation.

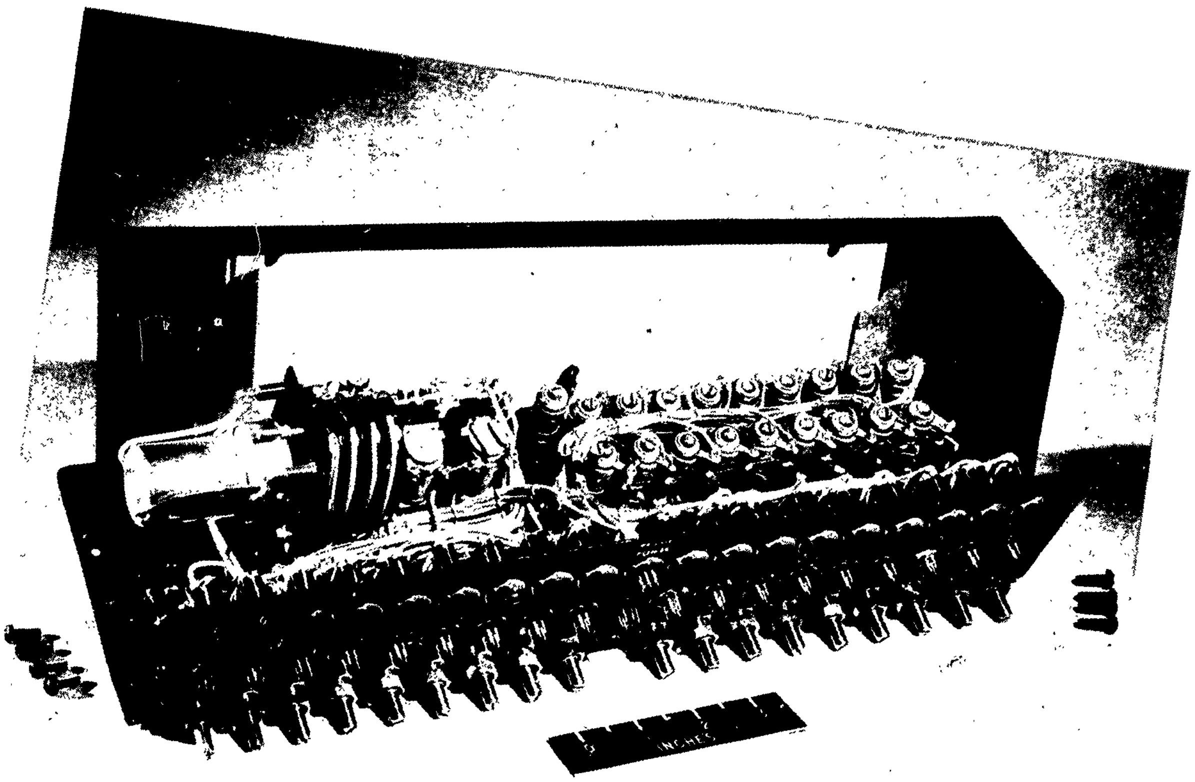


Figure P-1

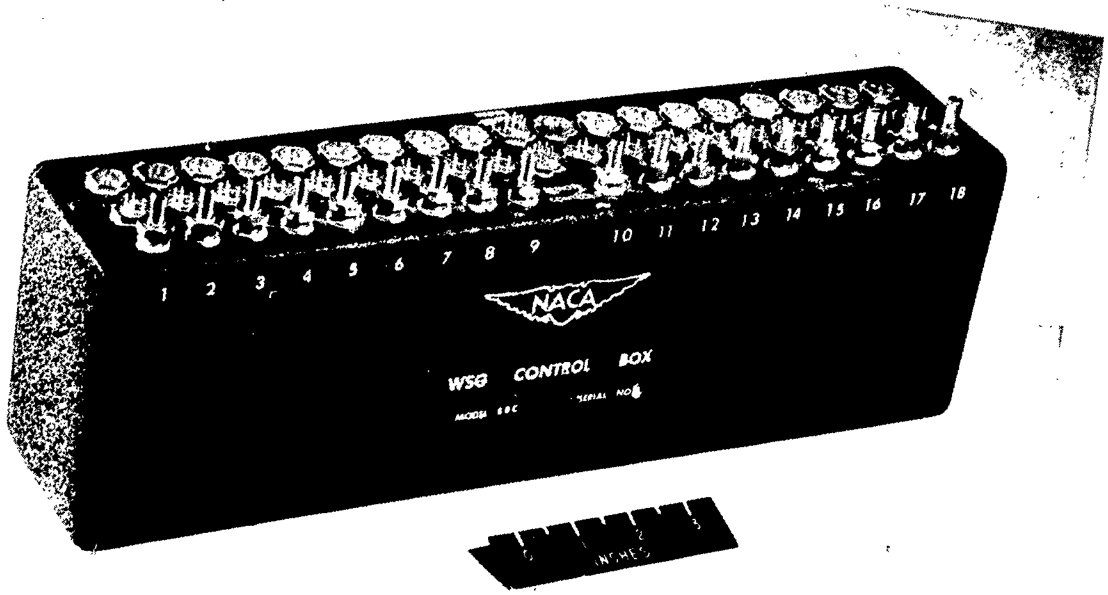


Figure P-2

DISTRIBUTION

Copies of AGARD publications may be obtained in the various countries at the addresses given below.

On peut se procurer des exemplaires des publications de l'AGARD aux adresses suivantes.

BELGIUM BELGIQUE	Centre National d'Etudes et de Recherches Aéronautiques 11, rue d'Egmont, Bruxelles
CANADA	Director of Scientific Information Service Defense Research Board Department of National Defense 'A' Building, Ottawa, Ontario
DENMARK DANEMARK	Military Research Board Defense Staff Kastellet, Copenhagen Ø
FRANCE	O.N.E.R.A. (Direction) 25, Avenue de la Division Leclerc Châtillon-sous-Bagneux (Seine)
GERMANY ALLEMAGNE	Wissenschaftliche Gesellschaft für Luftfahrt Zentralstelle der Luftfahrtdokumentation Munchen 64, Flughafen Attn: Dr. H.J. Rautenberg
GREECE GRECE	Greek National Defense General Staff B. MEO Athens
ICELAND ISLANDE	Director of Aviation c/o Flugrad Reykjavik
ITALY ITALIE	Centro Consultivo Studi e Ricerche Ministero Difesa-Aeronautica Via dei Pontefici 3 Roma
LUXEMBURG LUXEMBOURG	Obtainable through Belgium
NETHERLANDS PAYS BAS	Netherlands Delegation to AGARD Michiel de Ruyterweg 10 Delft

NORWAY NORVEGE	Mr. O. Blichner Norwegian Defence Research Establishment Kjeller per Lilleström
PORTUGAL	Col. J.A. de Almeida Viama (Delegado Nacional do 'AGARD') Direcção do Serviço de Material da F.A. Rua da Escola Politecnica, 42 Lisboa
TURKEY TURQUIE	Ministry of National Defence Ankara Attn. AGARD National Delegate
UNITED KINGDOM ROYAUME UNI	Ministry of Aviation T.I.L., Room 009A First Avenue House High Holborn London W.C.1
UNITED STATES ETATS UNIS	National Aeronautics and Space Administration (NASA) 1520 H Street, N.W. Washington 25, D.C.

Printed by Technical Editing and Reproduction Ltd
95 Great Portland St. London, W.1.

AGARD Report 319
North Atlantic Treaty Organization, Advisory Group for Aeronautical Research and Development
FLIGHT TEST TECHNIQUES AND INSTRUMENTATION FOR VTOL AIRCRAFT
Robert J. Tapscott
1961
16 pp. incl. 5 refs & 10 figs., plus 16 appendices

533.652.6:533.6.05

3c6d

A discussion is presented of the basic measurements made in flight with VTOL aircraft to explore the new regimes of flight involved and to develop design criteria and operating techniques in the new regimes. In many cases, the actual flight procedures discussed are similar to those used for other types of aircraft. The exploratory nature

P.T.O.

AGARD Report 319
North Atlantic Treaty Organization, Advisory Group for Aeronautical Research and Development
FLIGHT TEST TECHNIQUES AND INSTRUMENTATION FOR VTOL AIRCRAFT
Robert J. Tapscott
1961
16 pp. incl 5 refs & 10 figs., plus 16 appendices

533.652.6:533.6.05

3c6d

A discussion is presented of the basic measurements made in flight with VTOL aircraft to explore the new regimes of flight involved and to develop design criteria and operating techniques in the new regimes. In many cases, the actual flight procedures discussed are similar to those used for other types of aircraft. The exploratory nature

P.T.O.

AGARD Report 319
North Atlantic Treaty Organization, Advisory Group for Aeronautical Research and Development
FLIGHT TEST TECHNIQUES AND INSTRUMENTATION FOR VTOL AIRCRAFT
Robert J. Tapscott
1961
16 pp. incl. 5 refs & 10 figs., plus 16 appendices

533.652.6:533.6.05

3c6d

A discussion is presented of the basic measurements made in flight with VTOL aircraft to explore the new regimes of flight involved and to develop design criteria and operating techniques in the new regimes. In many cases, the actual flight procedures discussed are similar to those used for other types of aircraft. The exploratory nature

P.T.O.

AGARD Report 319
North Atlantic Treaty Organization, Advisory Group for Aeronautical Research and Development
FLIGHT TEST TECHNIQUES AND INSTRUMENTATION FOR VTOL AIRCRAFT
Robert J. Tapscott
1961
16 pp. incl 5 refs & 10 figs., plus 16 appendices

533.652.6:533.6.05

3c6d

A discussion is presented of the basic measurements made in flight with VTOL aircraft to explore the new regimes of flight involved and to develop design criteria and operating techniques in the new regimes. In many cases, the actual flight procedures discussed are similar to those used for other types of aircraft. The exploratory nature

P.T.O.

of the VTOL flight testing, however, frequently calls for special planning with respect to safe methods for conducting the flight tests, procedures for demonstrating the distinctive characteristics, and suitable recording instrumentation. The importance of pilot orientation in order that he may provide accurate observations and opinions to the engineer is discussed particularly in regard to the many qualitative aspects of the VTOL flight programs conducted to date.

This Report was presented at the Nineteenth Meeting of the AGARD Flight Mechanics Panel, held from 17-19 April 1961 in Paris, France

of the VTOL flight testing, however, frequently calls for special planning with respect to safe methods for conducting the flight tests, procedures for demonstrating the distinctive characteristics, and suitable recording instrumentation. The importance of pilot orientation in order that he may provide accurate observations and opinions to the engineer is discussed particularly in regard to the many qualitative aspects of the VTOL flight programs conducted to date.

This Report was presented at the Nineteenth Meeting of the AGARD Flight Mechanics Panel, held from 17-19 April 1961 in Paris, France

of the VTOL flight testing, however, frequently calls for special planning with respect to safe methods for conducting the flight tests, procedures for demonstrating the distinctive characteristics, and suitable recording instrumentation. The importance of pilot orientation in order that he may provide accurate observations and opinions to the engineer is discussed particularly in regard to the many qualitative aspects of the VTOL flight programs conducted to date.

This Report was presented at the Nineteenth Meeting of the AGARD Flight Mechanics Panel, held from 17-19 April 1961 in Paris, France

of the VTOL flight testing, however, frequently calls for special planning with respect to safe methods for conducting the flight tests, procedures for demonstrating the distinctive characteristics, and suitable recording instrumentation. The importance of pilot orientation in order that he may provide accurate observations and opinions to the engineer is discussed particularly in regard to the many qualitative aspects of the VTOL flight programs conducted to date.

This Report was presented at the Nineteenth Meeting of the AGARD Flight Mechanics Panel, held from 17-19 April 1961 in Paris, France